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California State Water Project

Volume IV Power and Pumping Facilities

Bulletin Number 200
November 1974

State of California
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BULLETIN No. 200

CALIFORNIA STATE WATER PROJECT

Volume IV

Power and Pumping Facilities

November 1974

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Secretary for Resources
The Resources Agency

RONALD REAGAN
Governor
State of California

JOHN R. TEERINK
Director
Department of Water Resources

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FOREWORD

This is the fourth of six volumes which record aspects of the planning, financing, design, construction, and operation of the California State Water Project. The subjects of the other volumes are: Volume I, History, Planning, and Early Progress; Volume II, Conveyance Facilities; Volume III, Storage Facilities; Volume V, Control Facilities; and Volume VI, Project Supplements.

The State Water Project conserves and distributes water to much of California's population and irrigated agriculture. It also provides electric power generation, flood control, water quality control, new recreational opportunities, and enhancement of sports fisheries and wildlife habitat.

Construction of the first phase of the State Water Project was completed in 1973. The $2.3 billion reimbursable cost is being repaid by the water users and other beneficiaries. It is expected that another $0.7 billion will be spent during the next decade to construct authorized facilities for full operation.

This volume summarizes the project power and pumping facilities. It describes the civil, mechanical, and electrical features of the plants, discharge lines, penstocks, outlet works, and intake structures. Geological conditions at each site are discussed and construction highlights are presented.

John R Teerink

John R. Teerink, *Director*
Department of Water Resources
The Resources Agency
State of California

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ABSTRACT

The power and pumping plants of the State Water Project are discussed in this volume. Five power plants (four of which are pumping-generating plants) and 13 pumping plants are now in operation. One power plant is in the design phase. Other plants are planned but not included in the discussion of the individual plants presented in this volume. Three of the plants were designed and constructed by other agencies. Two of these were partially funded by the Department of Water Resources as part of the Project, and the Department also is the operator of these facilities. The wide divergence in heads, flows, speeds, horsepower, and kilowatt ratings of various plants are presented in tabular form for ease of comparison. The plants are located throughout the Project over a distance of about 550 miles.

Equipment, systems, criteria, and codes common to all plants are discussed initially to avoid repetition in individual plant coverage. The more interesting and unique aspects of the design and construction details of each plant are discussed under the appropriate headings. Included are descriptions of structures, architectural treatment, discharge lines and penstocks, site geology, and equipment. Construction activities are also included.

The volume is written in the language of engineers and engineering geologists engaged in design and construction activities throughout project development. Highly technical discussions and extensive details are avoided in an attempt to interest the largest cross section of readers. Design analyses and alternatives studied generally are included whenever they are related to major decisions and unusual physical features. Difficulties which arose during construction or after start of operations also are discussed. These difficulties probably were no greater or less than encountered by others involved in similar major projects.

Consulting firms and boards were selected and retained by the Department to provide broad experience and expertise in several areas of project work. Extensive model-testing programs designed to ensure appropriate and economic design were utilized and supervised by the Department.

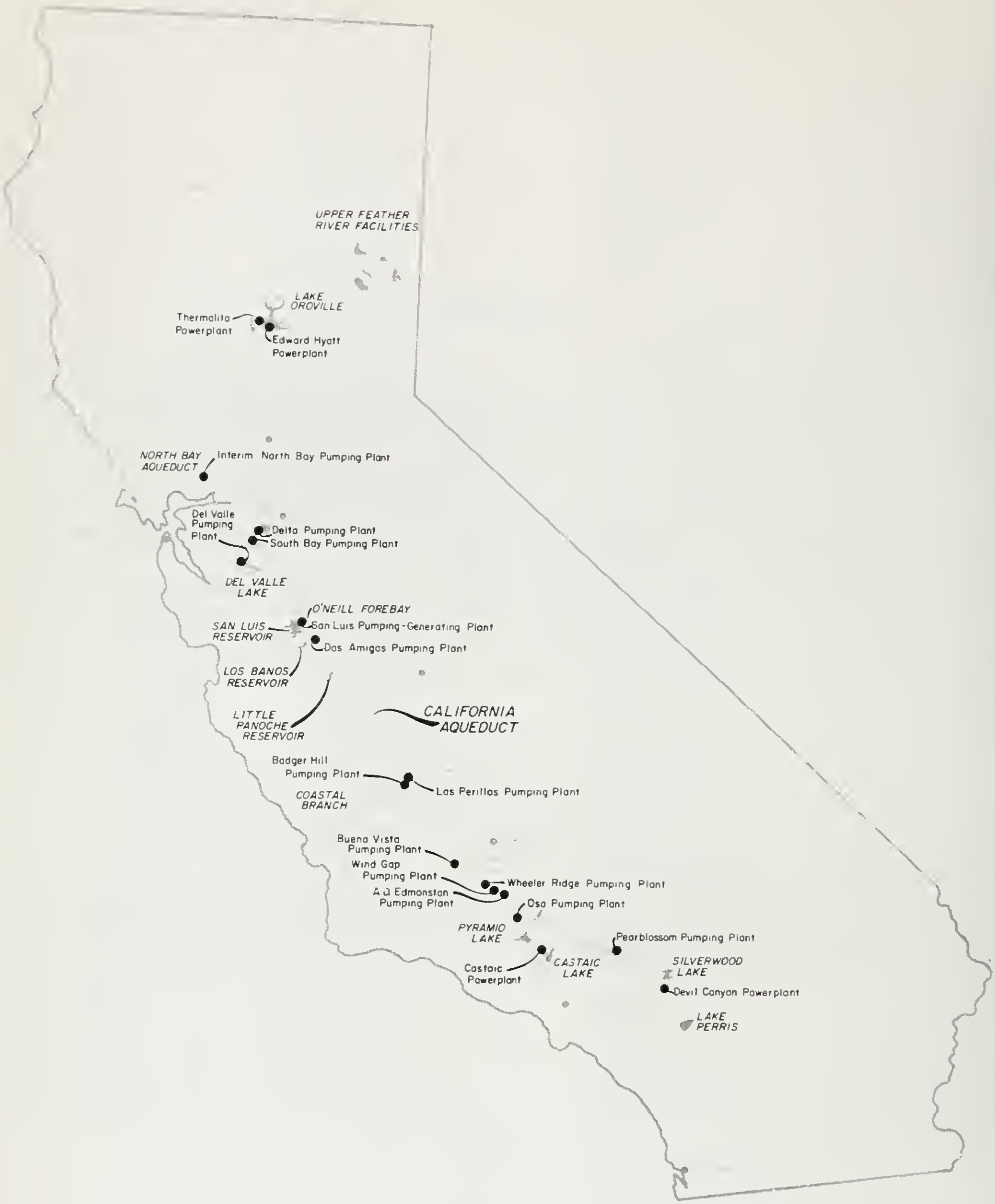


Figure 1. Location Map—State Water Project

CHAPTER I. GENERAL

Introduction

The design and certain characteristics of State Water Project power and pumping plants followed common criteria and design standards. These common criteria and design standards are the subject of this chapter. General information on the various plants of the Project is presented in Table 1. Design and conditions unique to individual plants are discussed in subsequent chapters.

Civil Features

General

The location (Figure 1) and layout of each power and pumping plant, including buildings and waterways, were determined on the basis of hydraulic and plant equipment requirements, site and local foundation conditions, and structural stability. In most cases, the final plant location was determined by establishing the point of economic balance between the cost of

TABLE 1. **Plant Data**

Plant	Number of units	Pump unit capacity (cubic feet per second)	Plant pumping capacity (cubic feet per second)	Motor rating (horsepower)	Unit speed (rpm)	Generator rating (MVA)	Normal static head (feet)	Penstock or discharge line diameter (feet)
Edward Hyatt	3[1]	1,870	5,610	173,000	189.5	115.0	410/676	2 @ 22′
	3[2]	--	--	--	200	123.2		
Thermalito	3[1]	3,000	9,000	40,000	112.5	30.6	85/102	3 @ 21′
	1[2]	--	--	--	138.5	34.3		1 @ 24′
North Bay Interim	1	5.8	32.8	350	1,775	--	320	1 @ 2′
	1	7.8		450	1,775			
	2	9.6		500	1,775			
South Bay								
1st Stage	1	15	105	1,250	1,200	--	566	1 @ 4.5′
	3	30		2,500	900			
2nd Stage	3	45	225	4,000	900	--	545	1 @ 5.5′
	2	45		3,500	900			
Del Valle	4	15/30	120	250	360/720[3]	--	0/38	1 @ 5′
Delta	2	350	10,303	11,250	400	--	244	1 @ 13.5′
	9	1,067		34,500	225			4 @ 15′
San Luis[4]	8[1]	1,375	11,000	63,000/34,000	150/120	53.0/34.0	99/327	4 @ 17.5′
Dos Amigos[4]	3	2,200	13,200	40,000	120	--	113	6 @ 18′
	3[5]	200/2,200		40,000	120			
Buena Vista	3	316	5,365	8,500	360	--	205	8 @ 9′
	7	631		17,000	257			
Wheeler Ridge	3	328	4,926	10,000	400	--	233	7 @ 9′
	6	657		20,000	277			
Wind Gap	3	315	4,725	22,000	514	--	518	1 @ 9.5′
	6	630		44,000	360			3 @ 12.5′
A. D. Edmonston	14	315	4,410	80,000	600	--	1,926	2 @ 12.5′ to 14′
Las Perillas	3	38	450	350	720	--	55	2 @ 6.5′
	2	112		1,000	450			
	1	112		1,000	600			
Badger Hill	3	38	450	1,000	900	--	151	2 @ 6.5′
	2	112		3,000	514			
	1	112		2,750	600			
Pearblossom	2	138	1,380	11,600	720	--	540	2 @ 9′
	4	276		22,500	514			
Devil Canyon	2[2]	--	--	--	277	63.0	1,368/1,433	1 @ 9.5′ to 8′
Oso	4	157	3,128	4,700	600	--	231	5 @ 9′
	4	625		18,750	300			
Castaic[6]	6[1]	2,885	17,300	350,000	257	250.0	830/1,098	6 @ 13.5′ to 9′
	1[2]	--	--	--	225	70.0		1 @ 7′ to 5′
Pyramid[7]	2[2]	--	--	--	300	82.6	699/757	2 @ 12′
Cottonwood[7]	1[2]	--	--	--	200	18.0	138/144	1 @ 11′

[1] Motor-generator
[2] Generator
[3] Direct-current motor with speed control
[4] Cooperative development with U.S. Bureau of Reclamation
[5] Deriaz pump
[6] Cooperative development with City of Los Angeles, Department of Water and Power
[7] In design

the required excavation versus cost of penstocks or discharge lines, including an estimated cost of head loss.

All plants, with exception of the North Bay Interim Pumping Plant, are indoor type. The indoor type of plant was selected based on economic studies which concluded: (1) electrical equipment would be less expensive because weatherproofing of all controls, terminals, and connections would not be required; (2) electrical equipment would be installed in a dust-free controlled environment which would prolong its life; and (3) cost of maintenance is less with an indoor plant because equipment maintenance can be scheduled irrespective of weather conditions.

Architecture

All plants conform to the State Water Project architectural motif established in January 1964 (see Volume VI of this bulletin). Exceptions are San Luis Pumping-Generating Plant and Dos Amigos Pumping Plant which were built by the U.S. Bureau of Reclamation and Castaic Powerplant built by the City of Los Angeles, Department of Water and Power.

Architectural finishes are used commensurate with the functions performed in specific areas. Liquid floor hardeners were applied to stairways and in rooms with electrical or mechanical equipment which can be affected by dust. Polyester terrazzo was used in oil rooms, the main floor, and toilet rooms. Vinyl asbestos tile was applied on floors in control rooms, offices, and automatic equipment rooms. On other floors, the concrete was not treated.

The substructure walls are either reinforced concrete or concrete block. The superstructure walls are either precast concrete panels or lightweight metal panels. The latter are used at plants located in areas of greater seismic activity. Lower superstructure walls are concrete block to provide a greater resistance to abuses. The lightweight metal walls are lined on the inside with insulated, perforated, metal panels to aid in noise control.

Acoustical plaster ceilings are provided in the control room and offices to reduce the noise level in these areas. Gypsum plaster was used in the toilet rooms. In all other areas, plain concrete, painted concrete, or metal decking was used.

Structures

A typical plant structure is shown on Figure 2. Plant structures are composed essentially of concrete and steel. Substructures for buildings are reinforced concrete and superstructures are structural steel with concrete block and sandwich-type metal panels or pre-

Figure 2. Typical Plant Structure—Wind Gap Pumping Plant

cast concrete panels. Rigid steel frames were used in order to minimize time required for construction of the superstructure and to provide for early installation of the bridge crane needed to handle machinery and equipment.

Plant substructures were constructed in two stages. The first stage included all the concrete required to form the main skeleton of the building. Blockouts were provided in the first-stage concrete for placement of draft tubes or suction elbow liners, valves, pumps or turbines, and motors or generators. Second-stage concrete was used to embed and support this equipment.

To eliminate excessive stress buildup in the longitudinal direction, the plant structures are divided into individual monoliths by expansion joints. Differential settlement of individual monoliths is prevented by concrete shear keys in these joints. Construction joints were used to facilitate placement of concrete. Water intrusion into the plant at the expansion joints is prevented by two PVC waterstops with a formed drain between them. Formed drains are connected through the plant internal drainage system to the dewatering sump.

Substructure

The substructures are reinforced concrete and consist mainly of heavy structural elements: walls, slabs, beams, and pilaster columns. Generally, the substructures are classified as shear wall type, rigid with little or no frame action. Their natural periods of vibration are short, and seismic forces are transmitted from the foundation and backfill with little amplification. Structural design of individual components was carried out using the "working-stress" method. The amount of reinforcing steel was based on computed stresses, control of shrinkage, and volumetric changes of concrete.

The overall length of a plant and the length of each monolith were determined by space requirements for pump or turbine units and size and geometry of the water passages. These dimensions were adjusted to allow maximum standardization of structural frames and other portions of the building.

Superstructure

The primary function of the superstructure is to shelter the equipment and support the bridge crane used for installing and maintaining the plant equipment. The structural steel consists of welded steel frames with rigid connections. Each frame column is anchored to the substructure with high-strength anchor bolts.

Lower portions of the exterior walls are grouted reinforced-concrete blocks. Remainder of the exterior walls, with a few exceptions, are metal sandwich-type panels, spanning vertically. The sandwich is made of a decorative exterior panel and a perforated interior panel, with fiberglass insulation between them. Reinforced-concrete panel walls were used in four plants: Edward Hyatt and Thermalito Powerplants and Delta and Del Valle Pumping Plants.

Superstructure columns support the crane runway. Rails extend the full length of the runway and are held in place by clips which allow longitudinal movement. Crane runway girders are discontinuous at expansion joints, and rocker bearings allow for bending rotation at the supports.

A composition-type roof is supported by a diaphragm of steel T-decking which is intermittently welded around the perimeter of each panel, at all supports, and between each T-section. The diaphragm was designed to carry lateral loads to the structural frame.

Stability

Stability analysis was made after the general arrangement of the plant was determined. Failure modes investigated included uplift, overturning, horizontal sliding, failure of foundation material in shear, and slip-circle failures. These modes were investigated for several conditions including construction, earthquake forces, as well as nonoperating and operating load conditions. For each failure mode, the Department of Water Resources set requirements for appropriate design safety factors.

Vertical forces considered in stability analysis were the dead weight of the structure, equipment weights, supported weights of earth and water, and uplift. The weight of movable equipment, such as crane loads and heavily loaded trucks, were included only where such loads decreased the stability of the structure.

Horizontal forces included pressures due to headwater, tailwater, earth, wind, and earthquakes. Forces due to waves also were included when the fetch was great enough to cause waves. Water pressure in the penstocks or discharge lines was included as hydraulic thrust. Wind and earthquake forces were applied under appropriate combinations of loading.

Soil strength parameters used in the analyses represented conservative values derived from tests of specimens obtained from borings at appropriate locations and depths. Applicable soil tests were made for each plant.

Design Loads

All structures were designed to withstand maximum dead, live, hydrostatic, wind, or earthquake loads. Dead loads considered in the design consisted of the weight of the structure, including walls, floors, partitions, roofs, and permanent equipment. Live loads included mobile equipment, stored materials, personnel and other moving objects, cranes and their loads, snow, and construction loads.

Live Loads. Floors generally were designed for an assumed uniform load, with additional provisions for large concentrated loads in designated areas. The assumed load was based on the functional requirements and the ratio of dead to live loads. Distribution of heavier loads over the floor was based on the following guidelines:

1. Methods normally used in structural design for distributing concentrated loads.

2. Standard specifications for Highway Bridges, American Association of State Highway Officials, Division III, Section 3, were used as standards for distributing wheel loads to slabs, beams, and girders. The H-20, standard, motor-truck loading was used for the design of gantry decks and similar areas.

Installation, erection, and maintenance conditions as well as impact and vibration also were taken into account.

Impact. Design of each plant considered the dynamic effect of moving loads to which structural members may be subjected. For ordinary conditions the impact factor, i.e., the multiplier to produce the total load for which all members were designed, was:

	Impact factor (percent)
Frames supporting elevators and hoisting apparatus	100
Slabs, beams, or frames supporting moving highway vehicles	10

Crane Loads. The maximum crane capacity differs from plant to plant. Preliminary information was used for the weight and wheel spacing. Maximum wheel loads were computed from the dead load of the crane and trolleys, plus its rated live load, with the load in position to produce maximum reaction. These were later compared and, if necessary, corrected in accordance with information furnished by the crane manufacturers.

Lateral force loads induced by trolley movement were taken as 10% of the trolley weight and the full capacity of its main hook, equally distributed to each rail. Likewise, 10% of the wheel loads, with the fully loaded crane in a position which would cause maximum wheel loads, was used as a longitudinal force induced by crane movement. A 10% impact allowance was added to these loads.

Wind Loads. Provision for stresses caused by wind were also incorporated in design. The design wind pressure varied between 15 and 35 pounds per square foot on the exposed vertical surfaces at different plants, depending on their geographical location.

Earthquakes. Design considerations for structures located in regions subject to seismic activities included provisions for earthquake stresses. Earthquake design criteria are described later in this chapter.

Live Load Reduction. Unit live load reduction was permitted under certain loading conditions. Beams, girders, trusses, columns, and footings have a reduction of 10% in unit live load where the supported area is between 200 and 300 square feet and 20% where the supported area is larger than 300 square feet. No reduction was allowed for storage and erection areas.

Design of columns in multistoried bays permits a further reduction in floor live load. It included total dead load, roof load, and a portion of the total specified floor live load above the column in question. Live load reduction is given in the following table:

Numbers of floors carried by column	Portion of live load on column
1	1.00
2	0.95
3	0.90
4	0.85
5	0.80
6 and over	0.75

Dynamic Loads. Dynamic loads generated by major equipment during operation of the plant are transmitted to the structure through the bearings and sole plates. These loads were secured from the manufacturers and subsequently used in the analysis of the substructure. Also, the effect of hydraulic transients (water hammer), caused by operation of the penstock or discharge line valves or wicket gates, was included in the design.

Earth Pressures. Static earth pressure and dynamic earth pressure caused by an earthquake were considered. Because of the rigidity of the plant structures, the minimum static lateral pressures were assumed to be at least equal to "at rest" pressures (see Bibliography).

Temperature. Changes in stresses due to expansion and contraction caused by rise and fall of ambient temperature were included in the analysis of important elements of the structure. Temperature stresses in massive substructures of the plant are controlled by expansion joints placed between monoliths and use of construction joints at designated places within each monolith.

Water Pressure. The ground water table in the structural backfill around the plants (with exception of two plants) was assumed to be at the same level as the water surface in a forebay of a pumping plant or in an afterbay of a power plant. Therefore, backfill always is considered to be fully saturated and the water pressure is accounted for under both static and dynamic load conditions.

Vibration. The substructures of all plants are heavy, and the ratio of concrete mass surrounding the main units to the rated capacity of the generators or motors exceeds the minimum values commonly accepted in practice. Vibration was not considered to require special attention.

Design Criteria

Codes and Standards. Applicable editions of the following codes and standards were used for design:

1. American Concrete Institute (ACI)
   a. "Building Code Requirements for Reinforced Concrete"
   b. "Manual of Standard Practice for Detailing Reinforced Concrete Structures"
2. American Institute of Steel Construction (AISC)
   a. "Manual of Steel Construction"
   b. "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings"
3. American Society for Testing and Materials (ASTM)
   a. Pertinent ASTM standards
4. American Welding Society (AWS)
   a. "Code for Welding in Building Construction" D1.0-66
5. Pacific Coast Building Association
   a. "Uniform Building Code"
6. American Association of State Highway Officials
   a. "Standards Specifications for Highway Bridges"
7. Federal
   a. U. S. Bureau of Reclamation's standards
   b. U. S. Army Corps of Engineers' standards
8. California Division of Industrial Safety
   a. Safety orders

Structural Concrete. Structural concrete was designed and detailed under ACI 318 and 315 published by the American Concrete Institute. The minimum compressive strength of concrete at 28 days was 3,000 pounds per square inch (psi), and the allowable design stress was 1,350 psi. All design was based on working stress analysis. Minimum compressive strength was 4,000 psi at 28 days for concrete used in temporary concrete bulkheads.

Reinforcing Steel. The reinforcing steel was intermediate-grade billet steel. Design stresses of 20,000 psi were used for tension, and 16,000 psi compression was used for vertical column reinforcement.

Structural Steel. Design of structural steel, using working stress method, was based on the AISC "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings", published by the American Institute of Steel Construction. Modulus of elasticity of steel was 29,000,000 psi and the coefficient of expansion .0000065 per degree Fahrenheit. Structural steel conformed to ASTM A36. Bolted connections were made with A325 high-strength bolts and specified as friction type. Welded connections conformed to American Welding Society "Code for Welding in Building Construction".

Earthquake Design

Recognizing the fact that many State Water Project facilities would be located in the most seismically active regions in California, the Department formed the Consulting Board for Earthquake Analysis consisting of prominent experts in the field of seismology, geology, structural engineering, and soil mechanics to evaluate possible earthquake hazards to the Project and to recommend seismic design criteria. Based upon a study of large California earthquakes, the Board submitted a report to the Department on November 19, 1962, containing recommendations and design criteria for the design of all principal project features. These criteria subsequently were updated by this Board. Recommendations by the Board and criteria applying to the design of major power and pumping plants were as follows:

1. The San Andreas and San Jacinto faults are recognized as the most probable source of damaging earthquakes.

2. It is assumed that large earthquakes will cause ground shaking that will, in the vicinity of the fault, have a maximum horizontal acceleration of 0.50g, and a maximum vertical acceleration of 0.33g, with a duration of strong shaking of 60 seconds.

3. Rigid structures with a natural period of vibration approaching zero will be subjected, independent of damping, to an acceleration equal to maximum ground acceleration (see average acceleration spectrum curve Figure 3). Power and pumping plant substructures and other structures which have more than 3% critical damping and a natural period of less than 0.15 seconds fall in this category and therefore will be subjected to a maximum uniform horizontal acceleration of 0.5g, and a maximum vertical acceleration of 0.33g, within the distance of approximately 12 miles from the two given faults.

4. Structures with a natural period of vibration exceeding 0.15 seconds may be subjected to acceleration exceeding maximum ground acceleration. It is appropriate to design these structures on the basis of spectrum curves (Figures 3 and 4) using appropriate factors of safety. (Figure 4 should be used to read the numerical values.)

5. It is assumed that ground motion will be of uniform intensity (acceleration 0.5g) over a distance of approximately 12 miles on each side of the fault. For

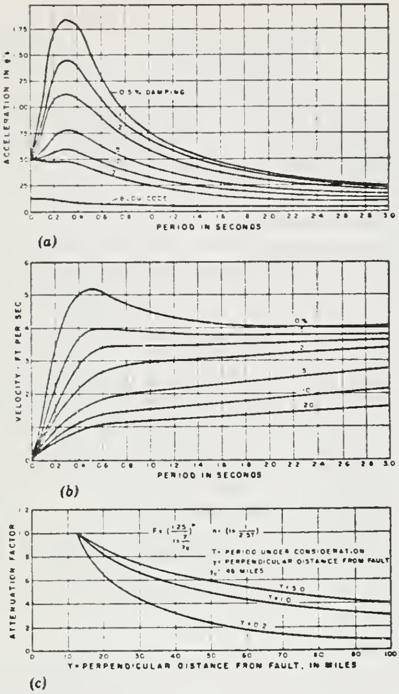


Figure 3. Average Accelerotion Spectrum Curves—Average Velocity Spectrum—Attenuation Factor for Ground Acceleration

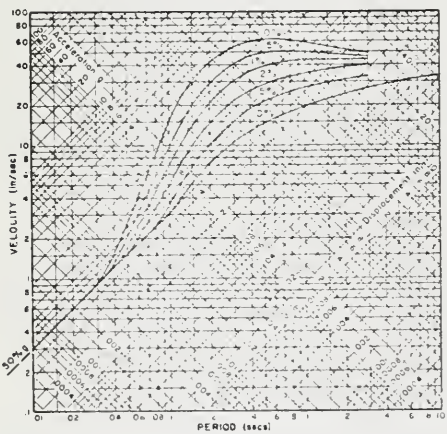


Figure 4. Averoge Spectrum

points farther than 12 miles from the fault, ground motion for periods less than 4 seconds will attenuate in accordance with the attenuation factor given on Figure 3. For periods greater than 4 seconds, the intensity of ground shaking can be considered uniform for distances considerably in excess of 12 miles from the fault (possibly 100 miles or more), and attenuation with distance is substantially less than that given by the formula in Figure 3.

6. For sites founded on sound rock, the intensity of ground shaking may be reduced, but each site should be considered a special case and reduction should be applied with caution.

7. For the design earthquake, ground motion governs the short period design at sites within 12 miles of the San Andreas and San Jacinto faults but, at greater distances, it is possible that ground shaking from a close small earthquake may be potentially more damaging than a distant large earthquake.

Design Spectra. Response spectrum values for ground motion inputs of a specific intensity are randomly distributed; i.e., two inputs having the same intensity, same duration, and same peak acceleration may have different spectrum values. A sufficiently large number of such inputs was considered satisfactory to define the frequency distribution of spectrum values. Figure 3 shows the average acceleration spectrum curves for damping values ranging from 0.5% to 20%. These spectrum curves were used in design of power and pumping plants. Applicable spectrum curves and judicious selection of allowable stresses in concrete and steel reflect a safe approach to the design of major hydroelectric plants in seismically active regions. Use of average acceleration spectrum curves and allowable design stresses relating to the ultimate strength of the material with so-called "ultimate" value being represented by the lower bound of the true failure stress is considered to be satisfactory for safe design.

The most important information needed to study dynamic characteristics of a structural system involves the determination of the natural frequency and damping characteristics. This can be accomplished by forced vibration testing of models, testing of existing structures, and mathematical methods. However, it is readily apparent that substructures of major power and pumping plants have a natural period of vibration approaching zero, and their acceleration caused by an earthquake approaches the ground acceleration. Design of substructures was based on this assumption. Design of superstructures was based on the acceleration values obtained from the spectrum curves.

Effect of Dynamic Loads. The effect of dynamic loads was approximated by the appropriate choice of equivalent static forces. These equivalent loads are governed by the dynamic behavior of the structure and the effects of backfill material and the water surrounding it. The main effects of dynamic loads include:

1. Increased lateral soil pressures on the substructure.
2. Hydrodynamic pressures on the substructure.
3. Increased foundation pressures.
4. Additional loads on the plant superstructure and substructure due to horizontal and vertical acceleration.
5. Dynamic loads on the main and auxiliary equipment and supporting structures.
6. Decreased slope stability of cuts and fills.

Special Design Considerations. Public safety and financial losses due to interrupted water and power service resulting from damage to a plant caused by an earthquake justify the use of seismic design criteria.

Seismicity and foundation conditions have a significant effect on design and construction of major hydro-installations. It is evident from research and the observed behavior of existing structures that the increase in loads during an earthquake depends mainly on the characteristics of the earthquake, geologic features of the area, local foundation conditions, and dynamic response characteristics of the structure.

Because plants normally are massive reinforced-concrete structures with heavy shear walls, the incremental cost of construction required by earthquake resistant design is quite small. The cost is considered to be a sound investment for safety and the operational reliability of the project.

Earthquake-resistant design depends on the specific function of a structure. Major power and pumping plants are designed to survive the anticipated earthquake without appreciable functional or structural damage.

Other special design considerations which pertain to the plants are:

Plant Substructure. All plants are subjected to hydrostatic pressures and were designed to be essentially watertight. No structural cracks are permitted in the substructure; however, slight cracking can be tolerated and a small amount of leakage can be taken care of by the internal drainage system.

Plant Superstructure. Most of the plant superstructures were constructed of rigid steel frames. Their design was based on spectral response curves because, in some cases, the response of the superstructure during an earthquake will exceed that of the ground acceleration. Considering ductility of the steel in such cases, the allowable steel stresses are permitted to exceed 1.33 times the ordinary building code value; however, a moderate margin below the yield stress is maintained.

Penstock and Discharge Line Articulation. A possibility of displacement and rocking of plant structures during a major earthquake was considered. Permanent displacements are more likely to occur on the alluvial foundations and their effects may be compounded by foundation rebound, consolidation, or both. Articulation has been provided for plants where displacement was considered possible. This articulation allows rotational movement as well as horizontal and vertical displacements between the plant structure and the conduit, thus precluding a rupture of the latter. Penstock articulation for Devil Canyon Powerplant (Figure 5) is typical. Should major leakage result from excessive movement of the articulation "spool" (conduit segment), water would drain through the watertight gallery and subsequently be discharged into the afterbay. Such galleries have been provided at plants located in areas of high seismicity to prevent flooding of the plant and equipment.

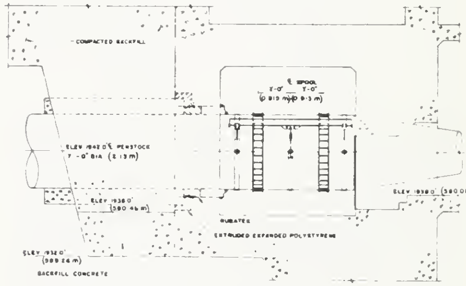


Figure 5. Penstock Articulation

Plant Equipment. Recommended seismic design criteria apply equally to design of plant equipment. Since some of the equipment furnished under earlier contracts was inadequate in strength, the Department has taken appropriate measures to render it more resistant to seismic forces. Most of the modifications were required in the electrical equipment, switchyards, cabinets, and other auxiliary equipment. Major equipment, including turbines, pumps, generators, and motors, was found to be inherently strong enough to sustain earthquake forces. It is noted that prior to recent earthquakes, design of this type of equipment to withstand large earthquake ground motions without damage was not common in the industries' "state-of-the-art."

Typical Steel Specifications for Penstocks and Discharge Pipelines

Steel manifolds, steel penstocks, and discharge pipeline systems were individually designed and fabricated from steel plate. Properties of steel plates conformed to ASTM specifications, as influenced by requirements for plate thicknesses, welding procedures, and availability of materials.

The following ASTM steel grades were used:

A283, Grade C	A441
A285, Grade C	A537, Grade A
A516, Grade 65	A572, Grade C45

The A285, A516, and A537 specifications are for pressure-vessel-quality steel plates. Pressure-vessel quality is used at power and pumping plants, while long conveyance pipelines generally use the structural grade.

Additional tests for quality control by the Charpy Impact Method were made on A537 steel to check the relative resistance of these plates to brittle cracking. Since these tests are influenced by heat, samples were held at the minimum temperature expected on the prototype. Minimum impact value was 15 foot-pounds at the specified temperature.

Typical design stresses for these steels were:

Loading Condition	*Primary Locations*	*Secondary Locations*
Normal	f_s = lesser of $\frac{1}{2} f_y$ or $\frac{1}{3} f_u$	f_s = lesser of $\frac{3}{4} f_y$ or $\frac{1}{2} f_u$
Emergency	f_s = lesser of $\frac{3}{4} f_y$ or $\frac{1}{2} f_u$	f_s = lesser of f_y or $\frac{3}{4} f_u$
Pressure test	$f_s = 0.75$ to $0.90\ f_y$	$f_s = 0.95\ f_y$

where f_s = maximum allowable fiber stresses in steel; f_y = minimum specified yield point stress; and f_u = ultimate stress as given in ASTM specification or as otherwise determined.

Primary locations include all points in the pipe wall which directly resist pressures exerted by the contained water. Secondary locations include all points outside the pipe wall, such as outer fibers of stiffener rings, thrust rings, and extreme fibers of wye branch reinforcement plates, where part or all of the fiber stress is due to bending moments and where yielding will not result in failure or leakage.

Minimum shell thickness was calculated by the following formulas:

$$(1)\quad t\ \text{min} = \frac{D + 20}{400}$$

$$(2)\quad t\ \text{min} = \frac{2.55R^2}{f_y}$$

where t = pipe shell thickness, in inches; D = pipe diameter, in inches; and R = pipe mean radius, in inches.

Formula (2) is based on analysis of an empty pipe resting on a rigid foundation.

All steel shell structures were hydrostatically proof-tested.

Welding Specifications on Discharge Pipelines and Penstocks. Special welding specifications were selected to control the quality of welding on all steel conduits. The following specifications were used:

1. American Welding Society, "Structural Welding Code for Welding in Building Construction", D1.0
2. American Welding Society, "Specifications for Welding Highway and Railway Bridges", D2.0
3. American Welding Society, "Structural Welding Code", D1.1-72, D1.1-Rev. 1-73 and D1-1-Rev. 2-74, which supersedes D1.0 and D2.0
4. American Society of Mechanical Engineers, "ASME Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels"

Welding specifications in the ASME Code were applied only to certain pressure vessels, such as the Pearblossom Pumping Plant air chambers. Otherwise, the aqueduct waterway conduits were designed and fabricated under a composite of AWS codes, since these pipes were subject to a wide range of gravity loads and vibrations. By using AWS codes, the Department exercised close overall control of the fabricator's welding procedures, including repair of weld defects.

Nondestructive tests to reveal weld and base metal defects were performed by ultrasonic and/or radiographic means. Ultrasonic testing complied with department standards; radiographic testing conformed to the requirements of AWS Specification D1.1.

Vibrational Control

Studies by the Department showed it necessary to determine a method of preventing resonant frequencies of vibration which could occur in pump discharge piping and manifolds.

Centrifugal pumps produce a forced vibration frequency in discharge pipes when the impeller vanes pass the tongue of the pump. A small nonuniform flow results as the water leaves this part of the pump, causing pressure waves to travel up the conduit until reflected. These pressure waves may coincide with the natural frequency of the pipeline and create an unacceptable resonance. To prevent the resonant condition, natural frequencies of the pipeline must be different from the vibration frequencies originating in the pump. This is achieved best by altering the physical restraints of the pipe shell.

As a result of these studies, all reflection points (openings, tapers, wye branches) were spaced at distances approximating a multiple of one-half wave length of the pipe's natural frequency, and stiffener rings were spaced at one-half wave length of a frequency equal to 1.414 times the forced frequency of the pump. This critierion was applied to buried, encased, and exposed pipes.

Wye Branches. At all plants, some form of branching of aqueduct pipe conduits is required which must sever structural continuity of the pipe shell in the intersections. The tension forces at free edges of the severed shell are resisted by welded crotch plate girders, cut to a shape approximating the intersection of the shells. These girders supply two perpendicular-force systems for full shell restraint. One system consists of vertical forces applied by the crotch plate as a curved beam, and the other system consists of horizontal forces which act normal to the plane of the crotch plate.

Forces normal to the plane of a plate can cause failure in plates with lamellar flaws. One solution used to prevent such failure at major plants has the pipe shell and girders welded to a round forged-steel bar bent to the shape of the shell plate intersection. The crotch plate fits against the outside surface of this round bar and resultants of all forces in the system pass through the center of the bar. In this way, none of the crotch plates is subjected to tensile stresses normal to its plane.

Another advantage to this assembly is that an extra reinforcing plate can be welded to the inside or "wet" side of the round bar to lower the high stresses in this area. This interior or "splitter plate" also can improve hydraulic conditions by directing the stream lines in the water to keep velocity changes through the wye branch at a minimum.

Main crotch girders are "U"-shaped and have been strengthened by one or two sets of semicircular exterior girders welded to the two ends of the crotch plates. These girders are fitted to the outside shell and provide clamping forces to resist elastic expansion of the entire assembly. Top and bottom intersections between girders and crotch plates also are welded to short, vertical, forged pins to resist lamellar tearing (Figures 6 and 7).

Wye branches and manifolds were designed to be underground and concrete-encased to provide anchorage and to resist earth loads. Since these sections would be fabricated from relatively thin material using high-strength steel, the pipe shells would expand under internal pressure and crack tight-fitting concrete encasements. To prevent this, manifolds were embedded in concrete under an internal pressure approximating 80% of operating pressure.

At many plants, sleeve couplings were used to connect articulated portions of the manifold sections. These circumferential joints could allow separation of the vessel from thrust forces developed during pressure tests. Before the concrete encasements were completed, temporary tie bars had to be welded across these joints.

Design Pressures. Design pressures used for these conduits were taken as the operating pressures increased by factors to approximate the pressure rise from normal operating conditions. Operating pressures were determined by the position of the energy gradeline with respect to the conduit. Factors for pressure rise varied with the type of pump or turbine, the rate of valve closure, and the frequency of dynamic load occurrence. At pumping plants, the dynamic effect factors were determined by the pressure upsurge following a power-failure condition. This was based on the assumption that the pump motors suddenly stopped operating and all control valves closed automatically at the specified rate. Typical design pressures in pumping systems were 1.20 to 1.40 times the operating pressure. At Devil Canyon Powerplant, because of the impulse wheel turbine characteristics, design pressure was only 1.11 times the operating pressure.

Design pressure was accommodated by shell structures proportioned by the allowable working stresses at normal loading conditions. Other infrequent conditions of operations which produced higher pressure conditions also were checked. Since these conditions for emergency-type loadings allowed the higher stress levels, they seldom governed the design.

Siphon Outlet Structures. Siphon outlet structures are provided at the upper ends of the pump discharge pipelines for Buena Vista, Wheeler Ridge, Wind Gap, Oso, and Pearblossom Pumping Plants. They are used in place of valves or gates to prevent backflow during pump outages and to provide for safer, more reliable, aqueduct operation. Additional advantages of these outlets are elimination of water leaking from canal gates into empty discharge conduits during maintenance, by the fast action of a siphon breaker compared to closure time for a large gate, and in lower maintenance costs for siphon breakers than for gates (Figure 8).

A series of hydraulic model studies on the performance of siphon outlet structures was made by the University of California at Davis during the design phase of the aqueduct. These tests determined the hydraulic characteristics of basic design configurations used for the aqueduct.

Each siphon outlet structure consists of concrete-encased siphon liners, concrete round-to-square transitions, and an open transition into the canal. The upstream end of each siphon liner is connected to a discharge pipeline, and each siphon outlet terminates under the water level in the stilling pool of the receiving channel.

At each siphon crest, the invert elevation is at least 1.0 foot higher than the maximum water surface elevation of the canal. During operation, each siphon flows over this crest at subatmospheric pressure which is maintained by small vacuum pumps located over the structure. When flow in a discharge pipeline is stopped, a 30-inch vacuum breaking valve at the siphon crown opens to admit air, raising the pressure in the siphon to atmospheric and preventing siphon action in either direction.

Prestressed-Concrete Cylinder Pipe for Discharge Pipelines

For construction of Oso and Pearblossom Pumping Plants, the specifications for the pump discharge pipeline conduits allowed alternative bidding schedules for furnishing and installing either steel pipe or prestressed-concrete cylinder pipe. In design details and criteria, this concrete pipe was similar to that used on long reaches of the aqueduct conveyance systems. Low bidders on both contracts stipulated prestressed-concrete cylinder pipe and this type of pipe was installed at both plants.

Prestressed-concrete cylinder pipe (PCCP) consists

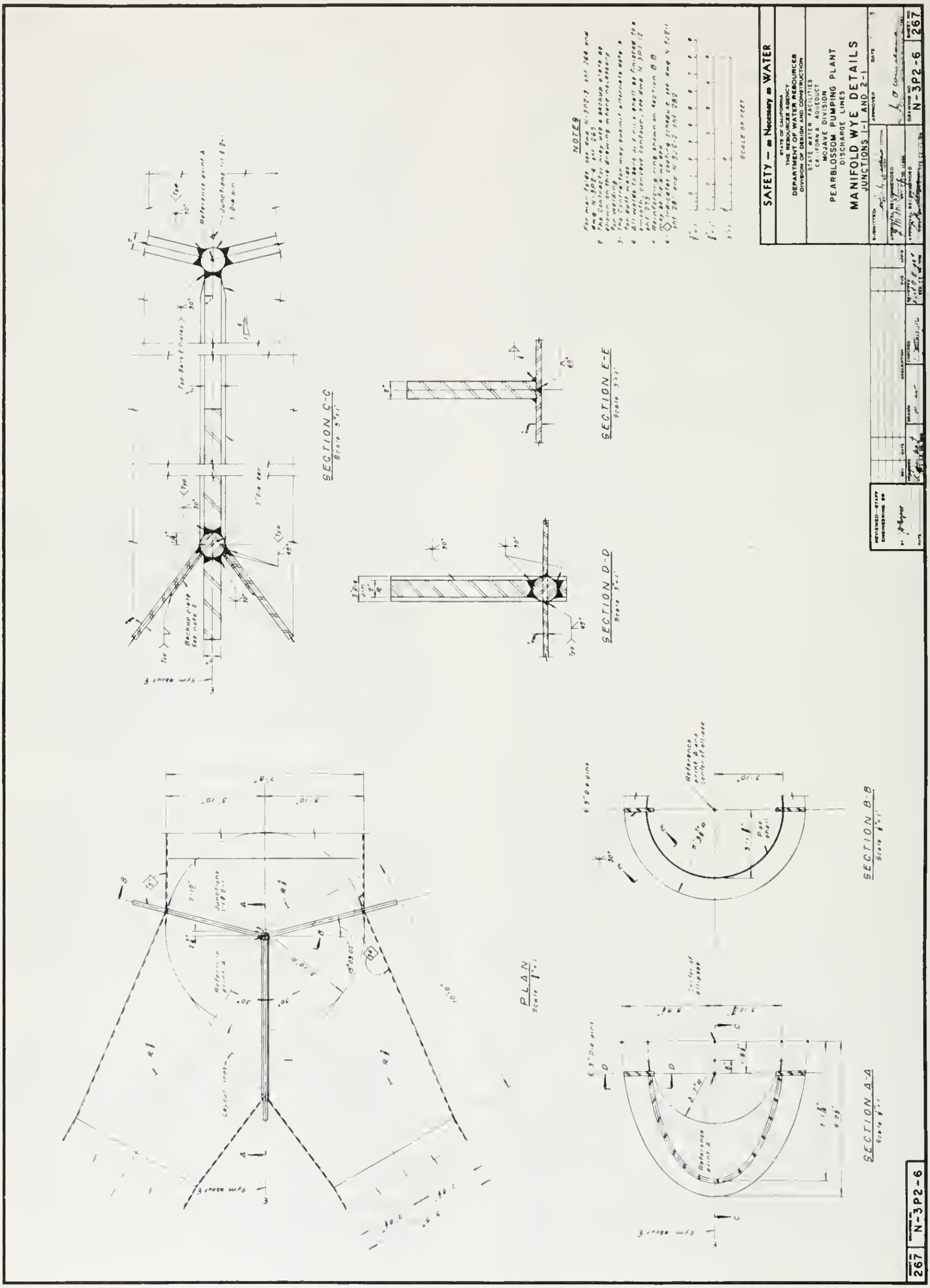


Figure 6. Typical Wye Branch—Junction Type I

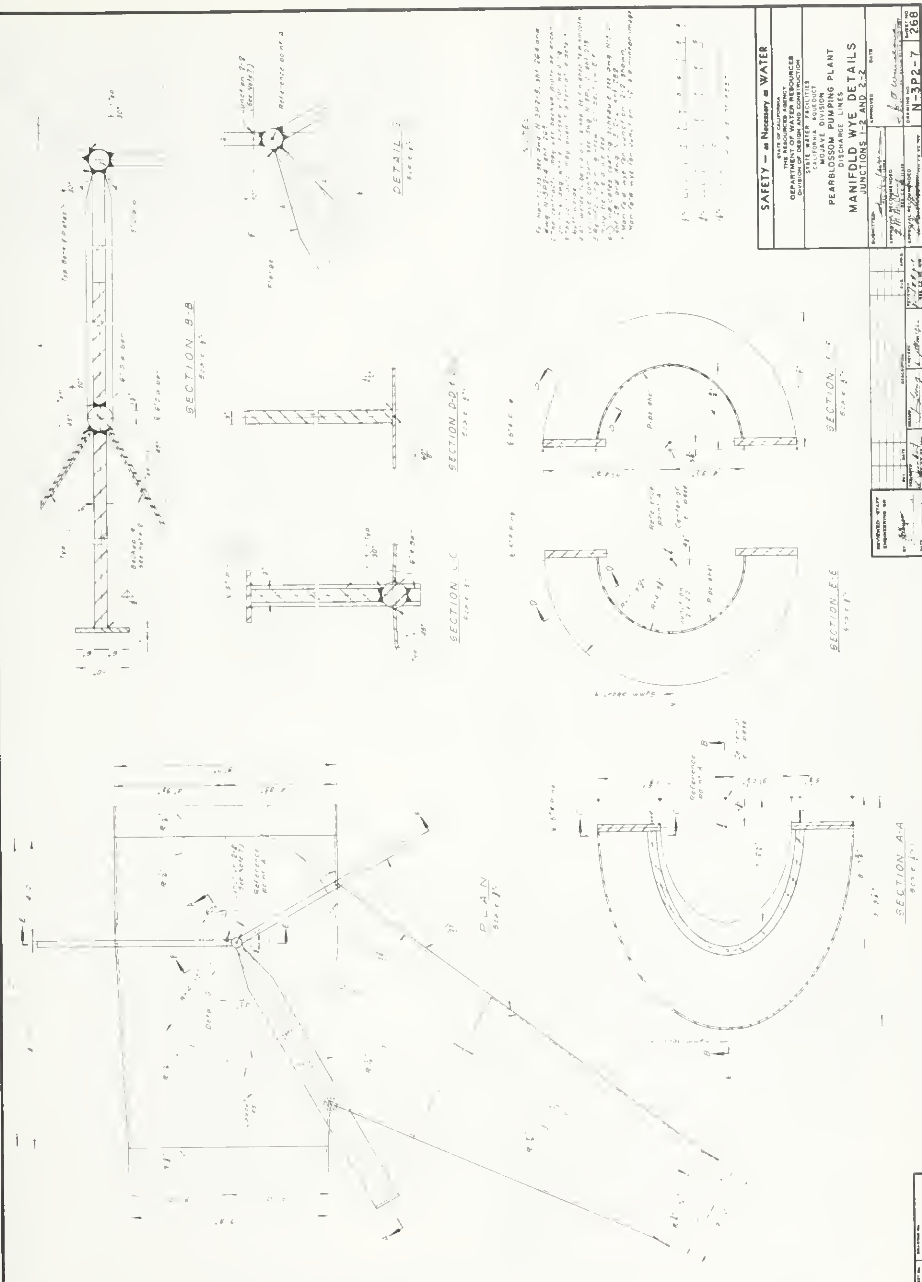


Figure 7. Typical Wye Branch—Junction Type 2

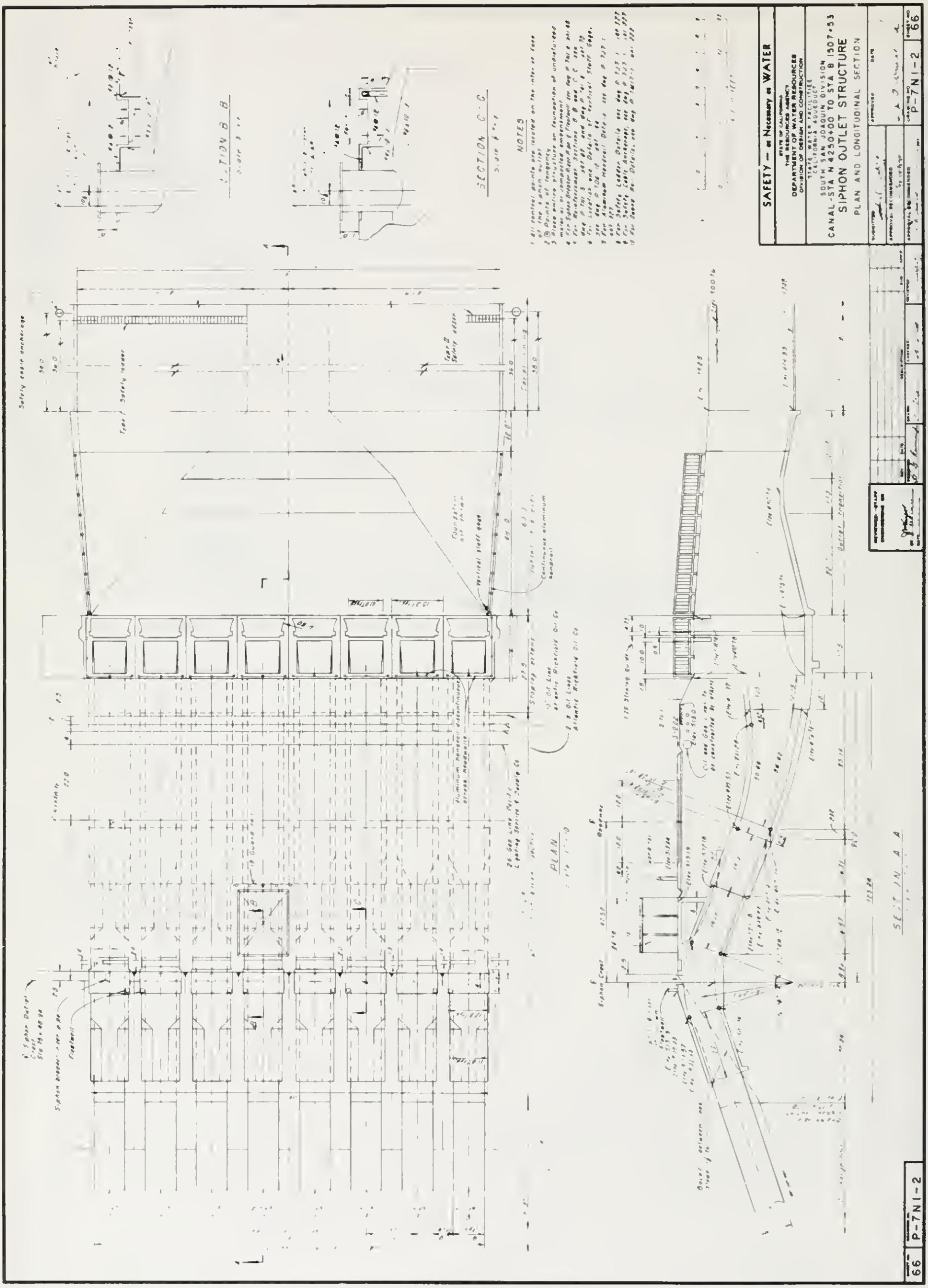


Figure 8. Typical Siphon Outlet

of a concrete core containing an embedded steel cylinder which has been wrapped with high-strength steel wire and covered with a coating of mortar (Figure 9). This pipe has been specified by the Department in accordance with AWWA Standard C301, modified to meet department standards.

Concrete core thickness (t_c) was varied for design purposes depending upon external loads acting on the pipe. Generally, three core thicknesses were considered for each pipe size:

Core Type	*Thickness (inches)*
Thin	$t_c = \frac{ID}{16}$
Standard	$t_c = \frac{ID}{12} - \frac{3}{4}$
Thick	$t_c = \frac{ID}{12} + 1$

where ID = pipe inside diameter, in inches.

Contractors were allowed to submit designs utilizing alternative core thicknesses. These variances were subject to departmental approval and allowed the pipe manufacturers to utilize existing outside forms.

Concrete compressive strength at 28 days (f'_c) for the core varied from 4,500 psi to 7,000 psi. The required strength depended upon the maximum stress caused by wire wrapping and external loading. Allowable compression in the core was 0.45 f'_c for normal loading conditions from design pressure and backfill and 0.60 f'_c for rare overload conditions, which include AASHO H-20 live loading at the ground surface over an empty pipe.

Tensile stress which could occur from external loading was allowed in the core at 7.5 $\sqrt{f'_c}$ for normal loading and 10 $\sqrt{f'_c}$ for overloading.

The Department required a minimum of seven days of water curing for the cores. Experience had shown that water curing produces a more durable concrete than conventional steam curing.

For the Oso and Pearblossom discharge pipelines, pipe for the steel alternative was designed to resist a calculated bursting pressure equal to 2.8 times normal design pressure, so the PCCP also was designed for the same bursting pressure. Normally, design for bursting pressure was not an important factor.

The steel cylinders are 16 gauge and welded to joint rings. Although the main purpose of the cylinders is to form a watertight membrane, their structural characteristics were considered in design of the pipe.

Joint ring design used ⅜-inch-thick steel bell rings and Carnegie-shape spigot rings, both rolled and then butt-welded. After welding, all rings were cold-expanded beyond their yield point to a standard circumference, because very close tolerances were required between mating bell and spigot rings to ensure watertight joints.

Thrusts and moments in the concrete core were calculated using coefficients which assumed that the earth, live, and dead loads cause a bulb-type pressure distribution on the pipe.

The pipe was designed for a 90-degree bedding. However, as a safety factor, bedding was specified to be a minimum of 120 degrees. Either compacted backfill or consolidated bedding material was used, depending upon material availability. One of the economies of using prestressed pipe was that compaction was not required above the bedding, except at road crossings and on the outside of horizontal bends.

Prestressing wire conforms to ASTM A227, Class II, or ASTM A648, Classes II or III. Class II wire was used for all PCCP discharge conduits except for the Pearblossom Pumping Plant second discharge line, which used a small amount of the higher strength Class III wire.

The wire was wrapped on the cores at a tension of ¾ of its minimum ultimate strength. The amount of wire required was based on moments and thrusts caused by both internal pressure and external loading.

The PCCP was designed for both a single wire wrap or a double wrap and the contractor was allowed an option, except where limitations in minimum wire spacing required a double-wrapped pipe. Because tensile strength of wire decreased as diameter increased, there was a balance point where the savings in wire by using two layers of small wire offset the increased labor involved in double-wrapping pipe. The option of a single or double wrap also gave the contractor more flexibility during periods of material shortages.

Upon completion of the wrapping operation, a dense mortar was applied to the outside of each pipe. This mortar protected the wire from damage and provided an alkaline environment to prevent corrosion of the wire. Mortar was from ¾-inch to 1 inch thick and applied by rotating brushes while the pipe was rotated on a turntable. The mortar thickness was included in the wall thickness used in the design calculations as it had a strength at least equal to the strength of the core. The extremely corrosive soil at Oso Pumping Plant required application of an epoxy coating over the mortar as added protection.

Because of the weight of individual pipe sections and the fact that bends were made with large-radius curves, anchorage of the pipe was not required. Beveled pipe for these bends was made by welding the spigot ring to the cylinder at the required angle. Maximum bevel allowed for any pipe section was a function of pipe diameter. "Pulling of joints", i.e., the opening of a pipe joint on one side of a pipe while closing it on the opposite side, was allowed only for extremely small changes in alignment or other minor field adjustments.

Articulation of Discharge Conduits by Special Suspended Pipe Spools. Foundation conditions on the California Aqueduct plants were not expected to provide full resistance to displacement-type movements

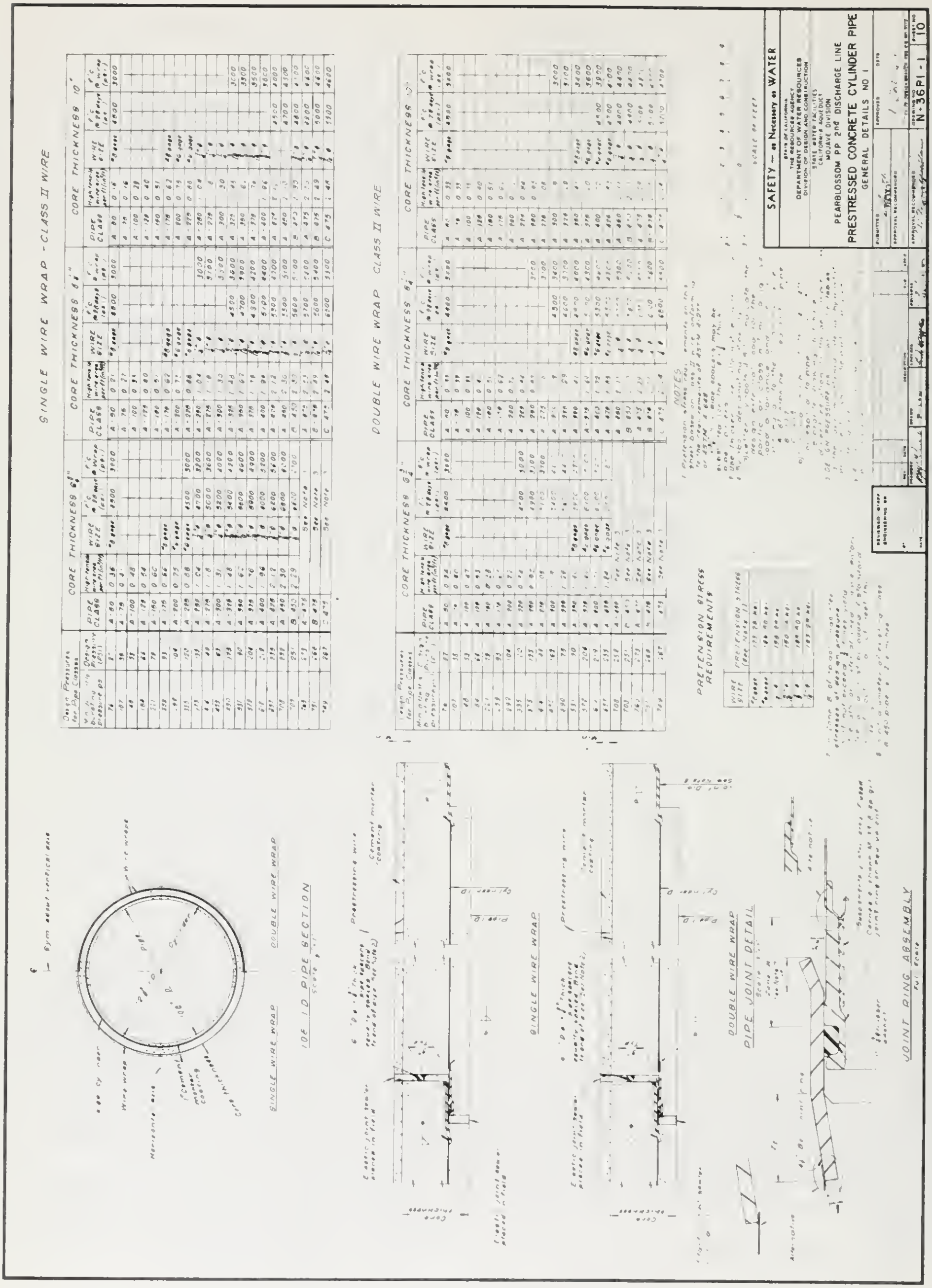


Figure 9. Typical Prestressed-Concrete Pipe Detail

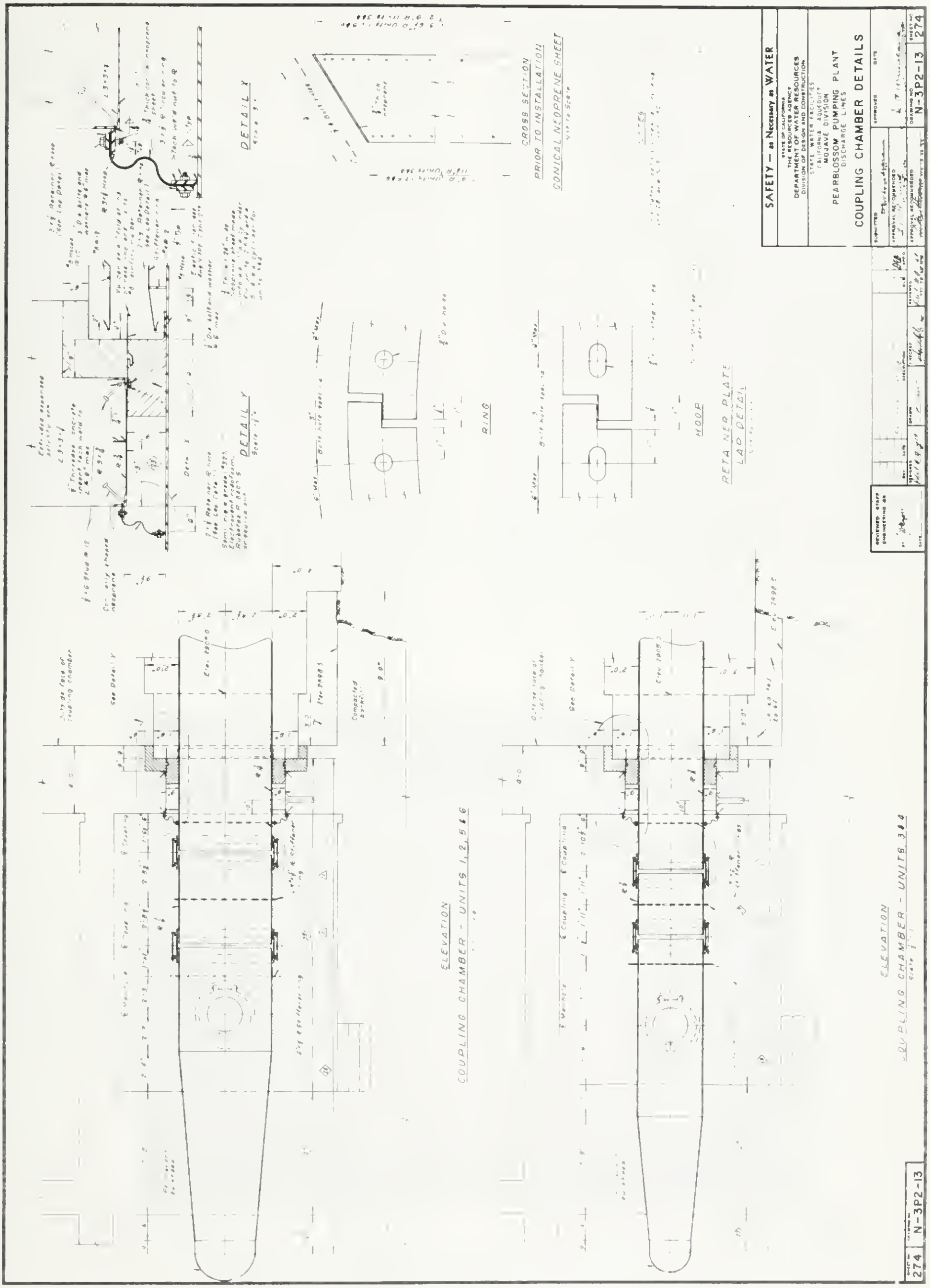


Figure 10. Typical Articulation Detail at Plants

between the main buildings and concrete-encased waterway conduits connected to the structures. These movements could result from shallow differential settlements, seismic action, or major deep-seated subsidences. A design was needed for a leak-free swivel which would allow a wide range of rotational and translational movement between the discharge taper, rigidly encased within the structure, and the conduits leading from the plant.

The Department's solution was to provide a mechanical pivot action or "universal joint" in the conduit between the two displacement points (Figure 10). This joint was achieved by using two special sleeve couplings with a short "spool" or pipe length suspended between them. The special couplings were necessary to allow the spool to move freely and absorb these displacements while remaining watertight.

This concept was used originally at the Delta Pumping Plant, where it has performed successfully. However, at other plant sites, some misalignment of spools occurred during the initial filling of the conduits. Water was not lost but the small misalignment was not acceptable. This led to installation of a suspension device at all plants, except Delta. This device supported the dead weight of the spool piece and yet allowed the full and original flexibility (Figure 11).

Special sleeve couplings (Figure 12) are conventional couplings with the middle ring lengthened to allow approximately a 6-inch longitudinal movement of the pipe ends while remaining watertight. These couplings will also allow an axial misalignment of 3 degrees.

Articulation of Waterway Conduits. Since earthquakes occur frequently in California, the juncture of the rigid plant structure and the conduits required special designs for articulation. Rigid pipe joints are subject to shearing failures and are considered unsatisfactory. Installation of special articulation joints allows freedom of movement, dampening of seismic accelerations, and permitted minor changes in conduit alignment during construction. In the case of steel pipe, sleeve-type couplings are used for all joints adjacent to rigid structures. For concrete pipe, sufficient flexibility is provided by "O" ring or "lock-joint"-type steel joint rings and rubber gaskets. In addition, cement mortar usually applied to fill pipe joint recesses has been deleted at Oso and Pearblossom Pumping Plants. At these plants, the severe articulation requirements precludes the use of cement mortar and a soft, elastic, field-placed, pipe-joint sealant is used instead.

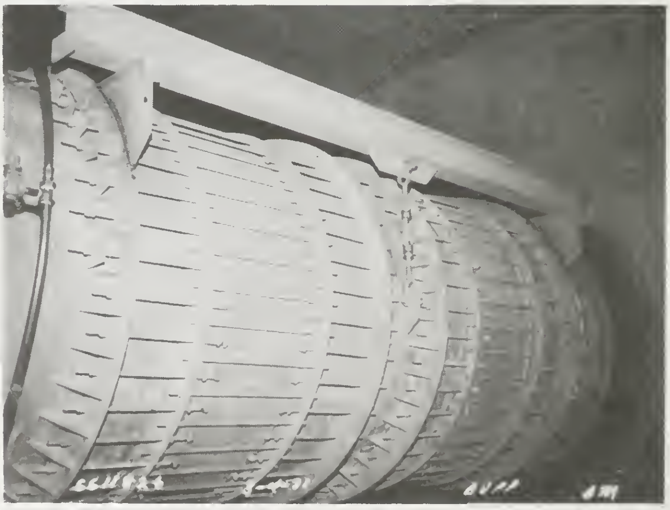


Figure 11. Suspended Spool Support System—Buena Vista Pumping Plant

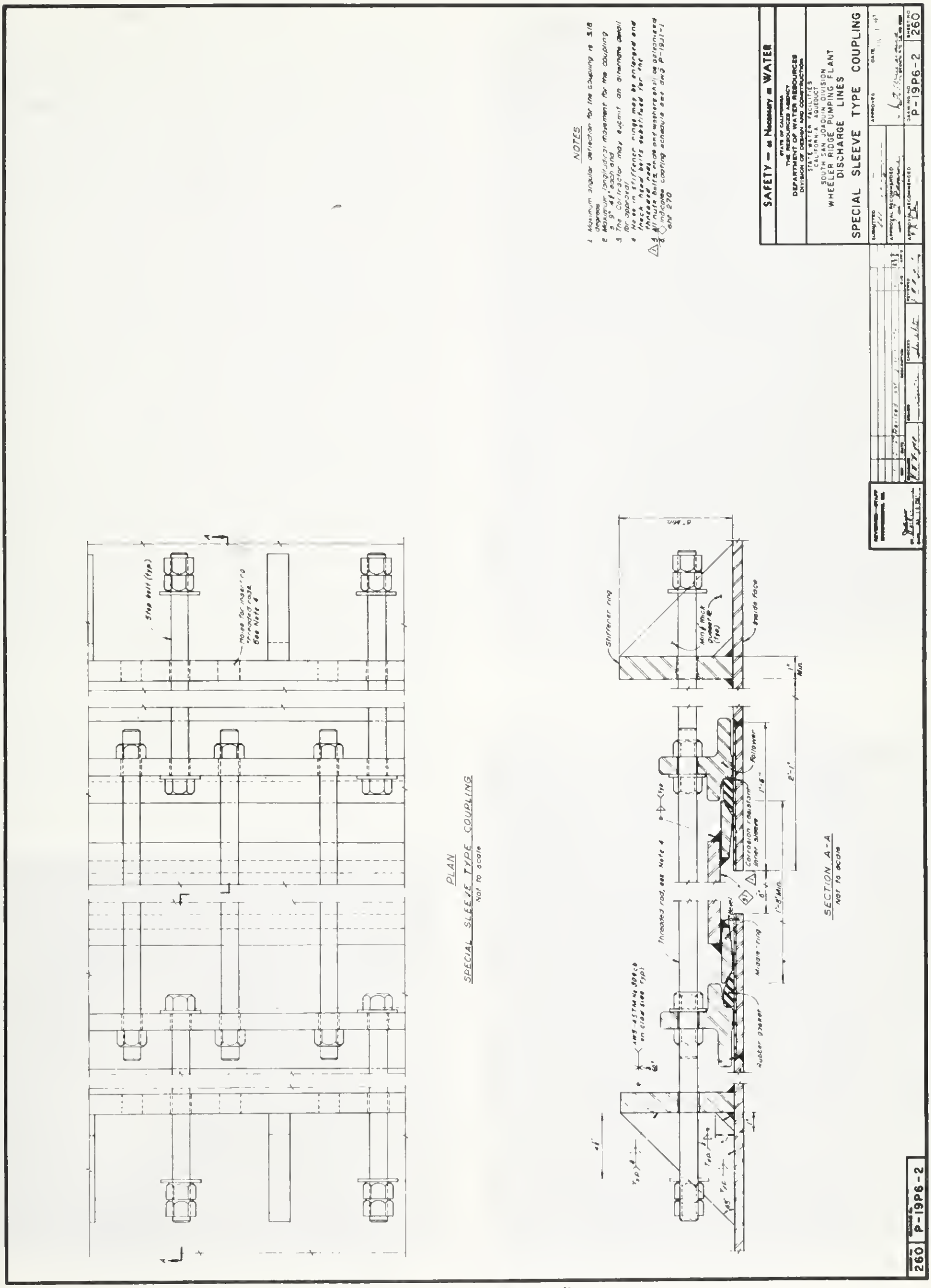


Figure 12. Special Sleeve Coupling

Figure 13. Multistage Pump—A. D. Edmonston Pumping Plant

Mechanical Features

General

At the time of manufacture, some of the major mechanical components required by the State Water Project were among the largest in the United States. Particularly noteworthy were the multistage pumps at A. D. Edmonston Pumping Plant (Figure 13), the pump-turbines and spherical valves at Edward Hyatt Powerplant (Figures 14 and 15), and the coaster gates at Hyatt and Angeles Tunnel intake structures.

The Project has utilized at least one of every major type of turbine generally produced, i.e., impulse, Francis, Kaplan, and high- and low-head pump-turbines with specific speeds ranging from 6 to 145. The larger project pumping plants also include practically every major type of multi- or single-stage pump, of either single-volute, double-volute, or diffuser type, and include pumps of both vertical and horizontal mounting. The specific speeds vary from 1,500 through 4,700 and the Department presently is studying tubular units in the 15,000 specific speed range.

The most significant mechanical engineering design effort was associated with Edward Hyatt and A. D. Edmonston plants. Edward Hyatt Powerplant was the first underground pumped-storage development in the United States. The reversible pump-turbine was just being introduced into the hydroelectric field when design was started. A. D. Edmonston Pumping Plant pumps more water higher than any other plant in the United States and contains the largest multistage pumps in this country.

To ensure reliability of operation of all the plants in the Project, exacting specifications were prepared for procurement of major hydraulic equipment. These specifications required detailed drawings from the manufacturer of all components for a rigorous review

Figure 14. Turbine Runner—Edward Hyatt Powerplant

Figure 15. Spherical Valve—Edward Hyatt Powerplant

by the Department. This review included independent stress analyses of the components to ensure that the stress levels were within the specified limits. In complicated configurations, such as pump and turbine casing covers and in spherical valve body halves and plugs, a computer analysis was employed using the finite element method (Figure 16 and Bibliography). Materials for each component were specified for the intended application, and the design was evaluated for ease in replacement of parts and for maintenance.

Rigorous inspection requirements and quality control were imposed on the manufacturer, and considerable nondestructive testing was required which increased the cost of the equipment a nominal amount. Notwithstanding, it was decided that these rigid requirements would prove economical in the long run since fewer outages would be likely to occur, thus assuring the Department could better meet its water delivery and power commitments.

To further assure the dependability of the equipment, a continuing comprehensive corrosion control program was initiated at the start of design. The most recent developments in corrosion control were investigated and applied to the equipment. The selection of method of control was based on economic considerations of capital expenditure, operation and repair costs, and revenue loss due to operation interruptions. Where applicable, corrosion-resistant materials, protective coatings, or corrosion-resistant claddings were used. On larger equipment, anodes or cathodic protection was the more economical selection.

During and following installation, major equipment and systems were tested extensively to establish field performance characteristics and operating reliability.

Design Criteria

Pumps, Turbines, and Pump-Turbines. Many factors were considered in determining the type, size, setting, speed, and number of units in a plant. Some of these factors were:

1. Head and volume of water to be handled
2. Length and configuration of pressure conduits
3. Specific speed
4. Efficiency
5. Cavitation
6. Draft-tube surges
7. Hydraulic transients (pressure and speed rise)
8. Stability
9. Part load capabilities
10. Manufacturer's capabilities (with regard to physical size)
11. Shipping limitations

Since these factors are closely interrelated, alternatives were considered and detailed studies were performed on the most promising. Some compromises had to be made as dictated by economics and state-of-the-art as related to equipment size and capability. Compromise, however, always followed the basic criteria of providing units at a reasonable cost while attaining the highest performance and reliability.

In the procurement of the main pumps, turbines, and pump-turbines, a minimum efficiency was specified at given conditions of head and capacity or power. In addition, the unit setting, speed, and head fluctuation were established. To ensure that the prototype would perform as specified, the manufacturer was required to build and test a model of a stated minimum size to determine the predicted prototype performance (Figures 17, 18, and 19).

The prototype characteristics were projected from the model test data by the laws of homology and by formulas set forth in the specifications. The manufacturer was required to meet the performance requirements specified prior to approval by the Department to proceed with the manufacture of the prototype. After installation, a unit of each type and size was tested to determine the prototype performance. For some plants, the flow rates for the large discharges

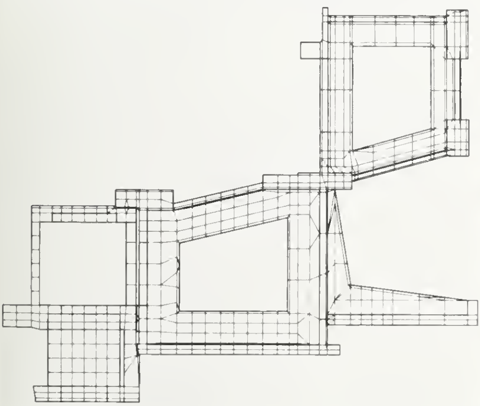


Figure 16. Finite Element Diagram of Hyatt Pump-Turbine Headcover—Half Section

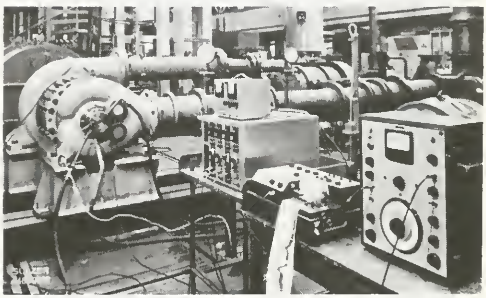


Figure 17. Model Test Stand—A. D. Edmonston Pumping Plant

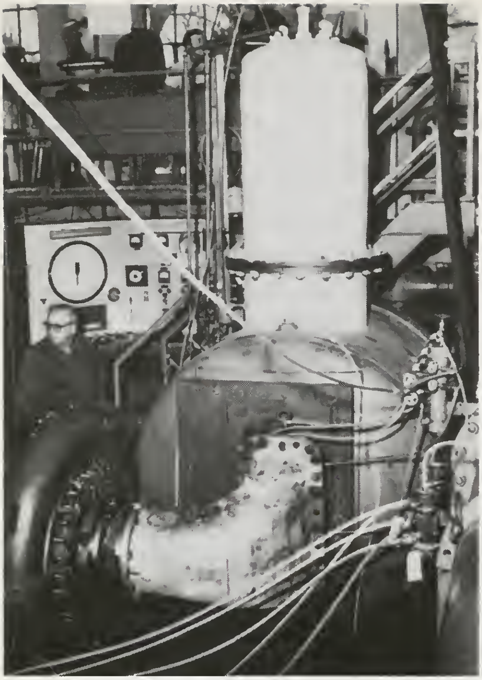


Figure 18. Model Test Stand—Edward Hyatt Powerplant

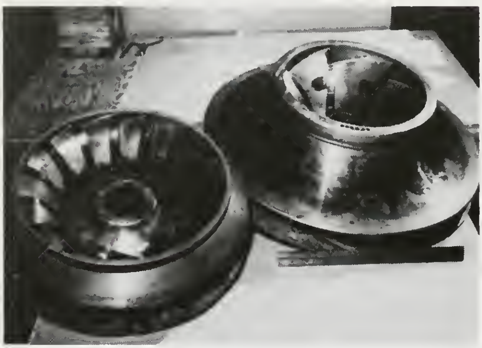


Figure 19. Runner Models—Edward Hyatt Powerplant

required for these site tests were obtained by the well-known methods of pressure-time (Gibson) and salt-velocity (Allen). At most pumping plants, however, discharge was determined by differential pressure taps on the suction elbows which were calibrated by model test. Due to inaccuracies inherent in field testing, a tolerance of 1½% was allowed in the efficiency guaranteed by the manufacturer. Conventional flowmeters are provided in most of the plants and ultrasonic flowmeters in some of the larger plants. The meters are for recording the flow in the Aqueduct and for revenue metering in some cases. Because of the superior precision of the ultrasonic meter, it is anticipated that it will be used to monitor the efficiency of the units and thereby establish the optimum time for repair of wearing rings, runners, and water passages. All meters were calibrated during the prototype performance tests. A particularly exacting test was performed at the Hyatt plant which compared the ultrasonic meter with the results of the Gibson test and calibrated Winter-Kennedy taps in the generating direction, and the results of the Allen salt-velocity and calibrated draft tubes in the pumping direction. The results of this test showed excellent correlation between the several methods of flow measurement.

The number and size of the units were determined for maximum flexibility in water and power delivery consistent with overall costs. Units of the Hyatt-Thermalito power complex were sized for optimum power delivery and pumped-storage operation for the two plants based upon a 60-year history of flow in the Feather River. In the South San Joaquin Division, pumps in the three plants upstream from A. D. Edmonston Pumping Plant were sized to provide capacities nominally equal to or twice that of a unit at Edmonston. With four pumping plants in an aqueduct length of approximately 42 miles between the first and last plant, sizing capacity of units as multiples of the capacity of the pumps at the Edmonston plant simplifies operation of the Aqueduct.

Governors. Selection of a governor for speed regulation of a turbine was limited to two alternatives: namely, mechanical-hydraulic and electrical. Both systems use a hydraulic system and accumulator to operate the unit's servomotors.

Although electrical governors were developed and in use prior to 1960, the time when selection had to be made, it was decided there was insufficient experience to establish the reliability of this newer design. Accordingly, mechanical-type governors were selected whose reliability had been proven in decades of use throughout the world (Figure 20).

To permit automatic and joint load control of the units, the governors are equipped with speed adjust transducers. The transducers receive a zero to 1-volt signal from the control center and adjust the load proportionally by direct actuation of the speed adjust mechanism on the governor.

Turbine Shutoff and Pump Discharge Valves. Valves were installed on each discharge line or penstock with the exception of Dos Amigos Pumping Plant and Thermalito Powerplant. The Thermalito units have very short individual penstocks and require only turbine wicket gates backed up by intake gates. In the Dos Amigos Pumping Plant, pumps are started against zero head and the discharge lines allowed to drain each time a pump is shut down. Typical per-

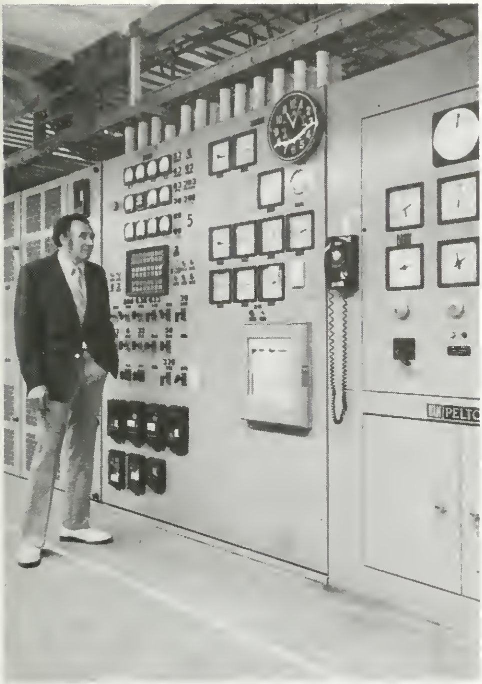


Figure 20. Governor Cabinet—Edward Hyatt Powerplant

formance curves were supplied by pump manufacturers (head, power, and efficiency v. discharge). These data were converted into a family of torque and speed curves by use of the laws of homology, and the overall feasibility of a pump start without a discharge valve was analyzed. Only at the Dos Amigos Plant was this found possible.

Where main valves are required, they provide the proper operating head for pump start-up and prevent drainage of water from the pump discharge line when a unit is shut down. They also provide isolation in the plants where several turbine or pump units are manifolded into one penstock or discharge line and provide shutoff for maintenance. All valves were designed for emergency closure against maximum flow at maximum head.

The selection of type and size of valve was based on economics, maintenance, reliability, and desired operating characteristics. Economics not only included the valve cost but also the structure costs to accommodate the valve, discharge line costs, operation and maintenance costs, and the cost of power and energy to overcome the head loss through the valve.

Valves considered in the analyses were the butterfly, double-seated spherical (both fixed and movable seats), single-seated spherical (fixed), cone, and check types. Cost, physical size, and consideration of operational flexibility confirmed that the cone, check, and single-seated spherical valves should be limited to use in the smaller plants.

The valve selection for the major plants was reduced therefore to the butterfly and spherical types (Figures 21 and 22). The butterfly valve is suitable primarily for lower head plants with double-seated

Figure 21. Butterfly Valve—Wheeler Ridge Pumping Plant

Figure 22. Spherical Valve—Edward Hyatt Powerplant

spherical valves preferred for higher head plants. The double-seated valve was the logical choice, since there is no appreciable difference in cost between the double- and single-seated valve, and the movable double-seated valve will permit replacement or repair of an operating seat without causing an outage on other units manifolded on the same penstocks or discharge line. At Buena Vista and Wheeler Ridge Pumping Plants, however, the manifolded three smaller units are equipped with butterfly valves since studies indicated that time for repair of these valves would not adversely affect the Department's water delivery commitments.

Oil is used exclusively throughout the Project as a source of power to operate the larger turbine shutoff and pump discharge valves (Figure 23). The large size of these systems made it uneconomical to use the more expensive noncorrodible materials required for water operation. Both water and oil, however, are separately used to activate the movable seats of spherical valves. For the Hyatt underground powerplant, water was chosen because penstock pressure did not require a back-up system to assure a reliable pressure source for the seats. Water also was selected for seat operation for Devil Canyon Powerplant, because the 2,000-psi oil accumulator system used for plug operation was judged too high for the seats. All the pumping plants are equipped with oil-operated seats because of the unavailability of clean, nonaggressive, and nonabrasive water, and a concern for potential maintenance problems associated with water operation.

Figure 23. Spherical Valve Oil Pressure Tank—Edward Hyatt Powerplant

Hydraulic Transients

Transients which occur under loss of electrical power or load rejection can result in severe damage if not considered in the design of equipment. This damage includes possible rupture of the penstock or discharge line caused by overpressure and collapse of the pipe due to underpressure.

The methods of analyzing hydraulic transients in turbine penstocks and pump discharge systems are well established. The Department used analytical, graphical, and computer methods to determine the design pressure requirements for its turbines, pumps, valves, penstocks, and discharge lines. Criteria for operating conditions considered for analysis were divided into two classifications: normal operation and emergency operation (see Bibliography).

Normal Pumping Mode Operation (Pumps or Pump-Turbines). For normal conditions of pump operation, the following were assumed to apply:

1. Pumps may be started or tripped manually or automatically throughout the entire range of operating heads existing at an installation.
2. Where shutoff valves are installed in a discharge line, the pump casing and portions of the pump discharge line between the pump and the valve are subjected to shutoff head.
3. Failure of power to all pump motors in a plant was assumed to occur a sufficient number of times during the operation of the plant to be considered a normal operating condition.
4. When a pump discharge system is equipped with pressure control devices (e.g., surge chambers, air chambers, check valves, surge suppressors), it was assumed that these devices will be properly designed and adjusted and function in the manner for which the equipment was designed.

The minimum pressure gradient along the length of a discharge line as a result of power failure was investigated to ensure that water column separation does not occur. This minimum gradient was used as a basis for the normal design of the pump discharge line to ensure against failure due to collapse. When a suitable pipeline profile could not be economically provided, and the computed minimum pressure gradient at any point in the discharge line fell below the vapor pressure of water, an increase in motor moment of inertia, or a pressure control device, is employed to prevent water column separation.

When check valves are present in a discharge line, the water-hammer effects were computed assuming that the check valve closes immediately upon the reversal of flow.

When a surge chamber was included in the design, the top of the chamber was established by adding sufficient freeboard to the highest upsurge attained to prevent spilling (or to avoid topping out in the tailrace tunnels of the underground Hyatt Powerplant). The bottom of the surge chamber was located at a sufficient distance below the lowest downsurge to prevent air from entering the discharge line.

With an air chamber present in a pump discharge line system (Pearblossom Pumping Plant), water hammer was determined by using the minimum volume of air in the air chamber at which point an air compressor normally would start up.

The maximum design head for a pump, valve, or discharge line inside a plant included the water-hammer effects for the normal condition operation listed above with a liberal factor of safety based upon the material (generally, ⅕ the ultimate strength or ⅓ the yield strength). Also, a conservative factor of safety was applied against collapse.

Emergency Conditions of Pumping Mode Operation. For emergency conditions, a malfunctioning of pressure control equipment was assumed as follows:

1. When surge suppressors or pressure relief valves are present, one is assumed to be inoperative.
2. If a check valve is used to shut off the return flow through a pump, the check valve closure of one unit was assumed to be delayed and to occur at the time of maximum reverse flow.
3. Where air inlet valves are included, they were assumed to be inoperative.
4. With an air chamber present in a pump discharge line system, the water-hammer effects were determined by using the minimum volume of air in the air chamber, at which point an emergency trip-out of all pumps on the discharge line was assumed to occur.

The head for which a pump, valve, or discharge line within the plant was designed included the water-hammer effects for the conditions of emergency operation listed above with a minimum factor of safety of 2 based on the ultimate strength or ¾ of the minimum yield strength of the material.

Normal Turbine Operation. For normal conditions of turbine operation, the following were assumed to apply:

1. Turbines operating at any gate position may be required to reject all loads up to 115% of the plant generating capacity.
2. When a turbine installation is equipped with any pressure control devices (e.g., surge chambers, governor control apparatus, cushioning stroke device), it was assumed that they will operate correctly.
3. The hydraulic transients were computed on the basis of maximum governor servomotor rate (minimum time).
4. The turbine gates may be closed at any time by the action of the governor head, by manual control of the main relay valve, or by the emergency solenoid shutdown device.
5. Criteria for penstock downsurge, upsurge, surge chamber design, and allowable stresses for normal operation is the same as previously noted for normal pump operation.

Emergency Conditions of Turbine Operation. For emergency conditions of turbine operation, the following were assumed to apply:

1. The servomotor cushioning stroke was assumed to be inoperative on one unit.
2. The maximum upsurge at the turbine was computed for maximum reservoir head condition for the part gate closure to zero gate position in $\frac{2L}{a}$ seconds (where L = penstock length and a = velocity of sound in water) on one unit at the maximum governor rate.
3. Turbines, valves, and other pressure control devices and the portions of the penstocks within the powerplant were designed for the emergency conditions with the same factor of safety as for operation of pumping units.

Hydraulic Transient Testing. After pump or turbine installation and as soon as practical after the start of operation, multiunit hydraulic transient tests were performed to verify design adequacy; establish optimum operating time for pressure control devices; and verify operational reliability of the equipment, systems, and integrated facilities.

Mechanical Standards and Codes

In the design of mechanical features, the Department complied with Titles 8, 19, and 24 of the California Administrative Code. Title 8 covers the Industrial Safety Orders such as the Unfired Pressure Vessel Safety Orders, Elevator Safety Orders, and the General Industrial Safety Orders. Title 19 covers the regulations of the Office of State Fire Marshal and sets the minimum standards to which equipment was designed for the prevention of fire and the protection of life and property. Title 24, the State Building Standards, regulates the design of air-conditioning, plumbing, and gas systems.

The following principal nongovernmental standards were used in the design of the mechanical systems and equipment:

1. American Society of Mechanical Engineers (ASME)
2. American Society for Testing and Materials (ASTM)

3. National Electrical Manufacturers Association (NEMA)
4. American Welding Society (AWS)
5. American Water Works Association (AWWA)
6. American Iron and Steel Institute (AISI)
7. Society of Automotive Engineers (SAE)
8. American Gear Manufacturers Association (AGMA)
9. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)
10. National Fire Protection Association (NFPA)
11. Underwriters' Laboratories (UL)
12. Hydraulic Institute

In addition, design standards and guide specifications published by governmental organizations, such as the U.S. Bureau of Reclamation and U.S. Army, Corps of Engineers, were used frequently as references.

Equipment and Systems Common to the Plants

The following service systems are common to most power and pumping plants. The design and type of a particular system may vary from plant to plant due to special requirements or conditions.

1. Compressed air system
2. Raw water system
3. Treated water system
4. Water fire-extinguishing system
5. Carbon dioxide fire-extinguishing system
6. Oil system
7. Drainage system
8. Dewatering system
9. Piezometer system
10. Plumbing and sewage system
11. Heating, ventilating, and air-conditioning system
12. Emergency generator system
13. Elevator
14. Equipment handling facilities

Compressed Air System. The service air systems provide air for hose outlets, instruments, air-operated valves, generator and motor brakes, sewage ejectors, hydropneumatic tanks, elimination of vibration and cavitation noise, and governors (Figure 24). In some plants, the service air systems are divided into subsystems of various pressures due to operational pressure requirements.

Air is supplied by compressors discharging into air receivers normally located in the service bay of the plants. Plants with pumps or pump-turbines which require that water be depressed for starting are provided with large air receivers to allow great quantities of air to be discharged into the unit in a short period of time (Figure 25).

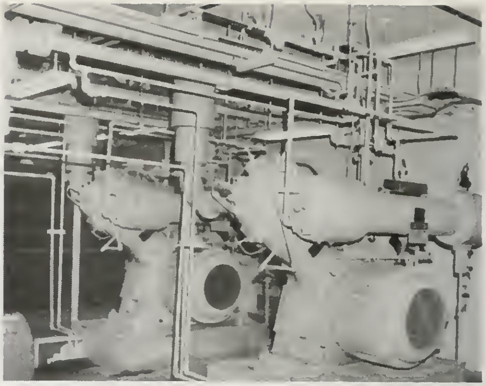


Figure 24. Air Compressors—Oso Pumping Plant

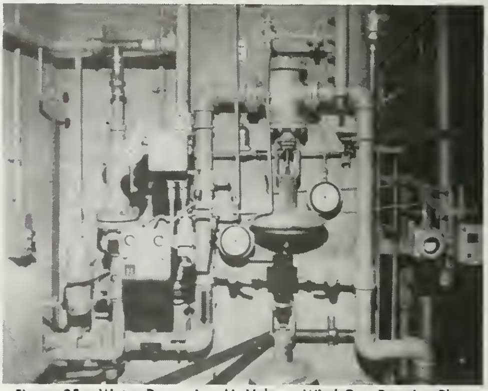


Figure 25. Water Depressing Air Valves—Wind Gap Pumping Plant

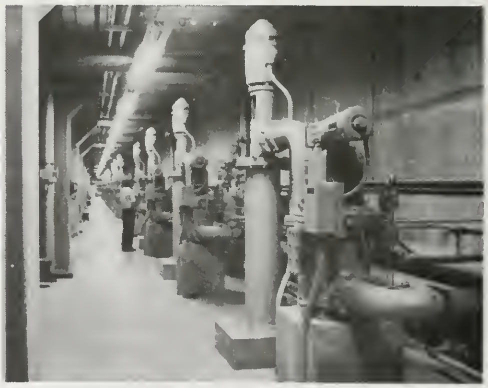


Figure 26. Unit Cooling Water Pumps—Wind Gap Pumping Plant

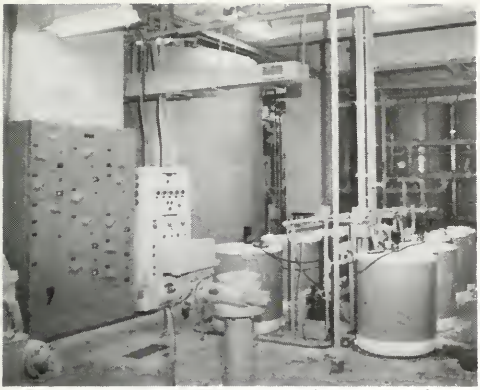


Figure 27. Water Treatment System—Wind Gap Pumping Plant

Figure 28. Water Treatment System—Wind Gap Pumping Plant—Angle View

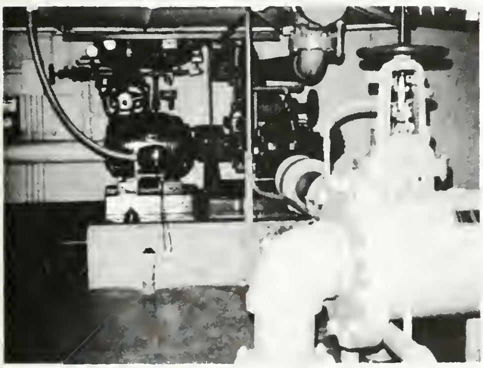


Figure 29. Fire Water Pump—Thermalito Powerplant

Raw Water System. Raw water is used to cool motor and generator coils and main bearings, pump and turbine wearing rings, air-conditioning units, and some air compressors and to supply the water treatment facilities (Figure 26).

Water normally is pumped from the forebay or afterbay or taken from the penstocks or discharge lines in the case of power or pumping plants with sufficient head to provide the required pressure. Engineering and economic studies were made to evaluate relative costs. At several plants, it was found that using a penstock or discharge line as a source was the most economical solution.

Treated Water System. A water treatment system provides potable water and water for use in the various systems where treatment is required for proper functioning. Water treatment normally is accomplished with a package unit consisting of sand filters, clarifiers, backwash storage tanks, clear well, pumps, storage tanks, and appurtenances. The system performs the functions of clarification, sterilization, taste and odor control, and filtration. The type of system installed depends on the quality of raw water available at each plant (Figures 27 and 28).

Water Fire-Extinguishing System. A water fire-extinguishing system consists of hydrants located in and around the plant. Transformer deluge systems, together with storage tanks and fire pumps, also were installed as required (Figure 29).

Carbon Dioxide Fire-Extinguishing System. A carbon dioxide fire-extinguishing system was installed to provide protection for the unit motors and generators and for the oil handling rooms. Normally an air housing has two separate headers: one connected to an initial discharge bank of CO_2 cylinders and the other to a delay discharge bank (Figure 30). The release of CO_2 is initiated by any of the following means·

1. Operation of a differential relay
2. Operation of a thermostat
3. Manual operation of a remote switch
4. Manual actuation at a cylinder bank

For the safety of personnel, an alarm bell sounds before CO_2 is released into the oil room. Pressure-actuated devices close fire doors in ventilation ducts and in the passageway between the oil rooms. All electrical apparatus in the vicinity, except lights, are de-energized upon release of CO_2.

Oil System. Lubricating oil (turbine and hydraulic oil) with rust and oxidation inhibitors is used for the unit bearings, for control of turbine blades and wicket gates, and for operating pump discharge and turbine shutoff valves.

Figure 30. Carbon Dioxide Fire-Extinguishing System—Oso Pumping Plant

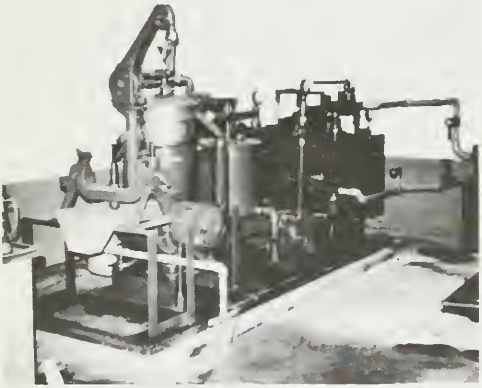


Figure 31. Transformer Oil Purifier—Thermalito Powerplant

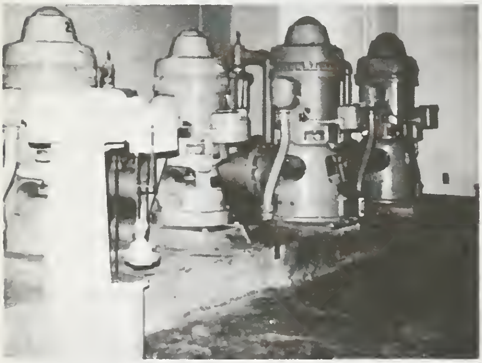


Figure 32. Drainage and Dewatering Pumps—Edward Hyatt Powerplant

The lubricating oil handling system includes transfer pumps, purifiers, and storage tanks. In some plants, provisions were made for storage and purification of insulating tranformer oil; in others, the oil is delivered when needed and purified with portable units (Figure 31).

Drainage System. The plant gravity drainage system provides for surface drainage of all floors, drainage of the generator or motor housing, seepage through walls, leakage through expansion joints, and drainage from mechanical equipment. The floor and equipment drain lines usually are connected to a header leading to the main drainage sump. Acid waste is piped to a separate sump in some plants. In oil rooms and transformer vaults, chilling drains are used and normally are piped to a separate sump. Separate gravity drainage systems are provided in many pumping plants for the discharge line coupling galleries. Piping is installed with a slope of 1 to 2% toward each sump, and all pipes entering each sump are provided with flap valves.

Drainage pumps are usually vertical turbine type, directly connected to a vertical, hollow-shaft, electric motor. Generally, two equal-size pumps are installed in parallel, sized such that one pump is capable of handling all drainage requirements with the second pump used for standby service (Figure 32).

Dewatering System. The dewatering system includes all valves and piping necessary to drain the turbines or pumps into the station sump. Normally two pumps, including one as standby, are installed. The pumps are similar in type and duty to the gravity drainage pumps described previously. Where separate drainage and dewatering sumps were provided, check valves were installed through the common wall to allow overflow from one sump to the other.

Piezometer System. Piezometer taps commonly are provided at various locations in the waterway of each turbine or pump and throughout various auxiliary systems for measurement of pressure. Piezometer taps which are embedded or otherwise inaccessible are piped to convenient locations for connection to pressure measuring equipment. Piezometer pipe ring headers are used, where appropriate, for pressure averaging.

Piezometer taps across penstock reducing sections, pump suction elbows, and turbine cases (Winter-Kennedy taps) are suitable for flowmetering after calibration. Calibration of the flowmeter taps was either done by the Gibson or salt-velocity method as a part of the efficiency testing or, in the case of the suction elbow, by flowmeter coefficients established by pump model studies.

Plumbing and Sewage System. Water is supplied to the plumbing system from the treated water system. Waste normally flows by gravity to the septic tank or sewage ejectors. The septic tank and sewage treatment facilities at some installations are located contiguous to, rather than in, the plant. Where the septic tank is located in the plant, septic effluent is pumped automatically from the tank into a sewage disposal system (Figure 33).

Heating, Ventilating, and Air-Conditioning System. The air-conditioning system is either of the central- or package-type refrigeration unit with electric heating coils for winter heating. The central-type system is installed with large fans and duct work which circulate the air through the plant, utilizing either refrigeration water chillers or reservoir water for cooling (Figure 34). Package-type refrigeration units are of the water-cooled or air-cooled condenser types and are located as necessary throughout the plant. A few smaller plants have evaporative cooling.

Emergency Generator System. Plants are provided with emergency engine-generator sets together with fuel storage tanks, interconnecting piping, and electrical controls to furnish standby power if there is an interruption of normal power supply. All engines are liquefied petroleum gas or diesel-fueled.

Elevator. In most plants, an electric freight elevator with fully automatic controls is installed in the service bay with landings on all floors. They are either underslung or overhead machinery type depending on requirements of each plant.

Equipment-Handling Facilities. At each major plant, traveling cranes are provided to lift and transport pumps, turbines, motors, generators, discharge and shutoff valves, and other miscellaneous equipment during installation, maintenance, and repair (Figure 35). Indoor plants are provided with overhead bridge cranes of conventional design. Where bulkhead-type gates are provided on the pump suction tubes and turbine draft tubes and intakes, gantry-type cranes are installed.

Design requirements for cranes, such as capacity and speed for the main and auxiliary hoists, were determined from the plant and equipment requirements and are listed in the chapters for the particular plant. Bridge cranes are required to meet applicable structural requirements of American Iron and Steel Institute Standard No. 6. Gantry cranes are required to meet the applicable requirement of Electric Overhead Crane Institute Specification No. 61. Bridge and gantry clearances are as required by the "American Standard Safety Code for Cranes, Derricks and Hoists" and applicable sections of the "General Industrial Safety Orders" of the State of California.

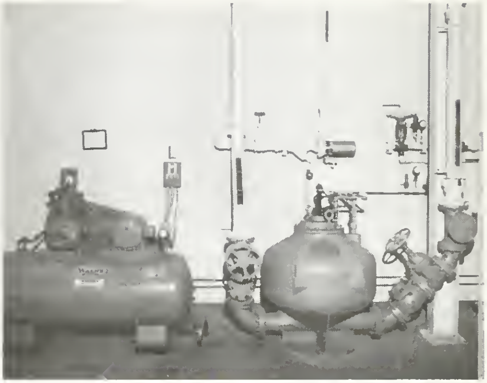


Figure 33. Sewage Ejector—Las Perillas Pumping Plant

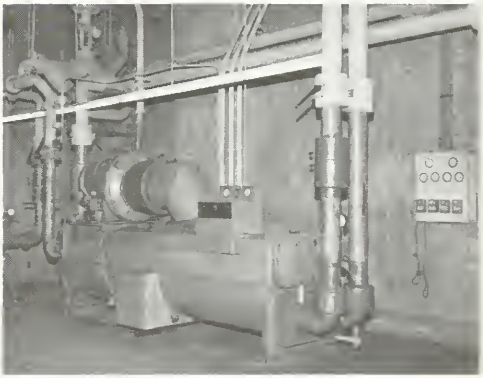


Figure 34. Refrigeration Compressor—Edward Hyatt Powerplant

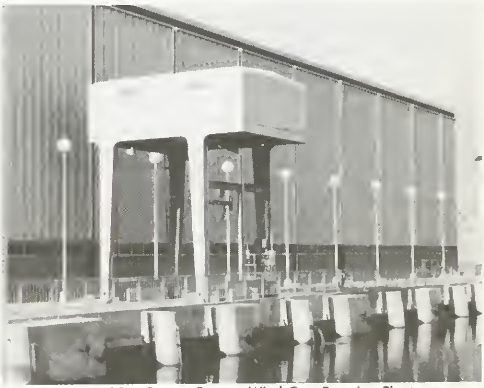


Figure 35. Gantry Crane—Wind Gap Pumping Plant

Siphon Outlet Valve

Incorporated in the siphon outlet structure at the end of each discharge line at Dos Amigos, Buena Vista, Wheeler Ridge, Wind Gap, Oso, and Pearblossom Pumping Plants is one siphon breaker valve. The valve is used to isolate the siphon from atmospheric pressure when pumping and to admit air when not pumping (Figure 36).

In the pumping mode, the siphon valve is closed and the trapped air in the crown of the siphon is removed with vacuum pumps. This reduces the head loss through the siphon, resulting in a lower head against which the pump must operate. When the pump is shut down, the siphon valve opens to admit air into the siphon to prevent backflow from the Aqueduct.

Each valve consists of a cast-steel body and top, with neoprene gaskets for the cast-steel spool. The spool has stainless-steel seats and a stainless-steel stem. A pneumatic cylinder mounted on top of the valve, connected to the stem, raises the spool against the seals, closing the valve. In the event of an electrical power failure, the weight of the spool is sufficient to open the valve.

A control house located adjacent to the siphon valves contains three vacuum pumps, two air compressor-receiver units, and one motor control center to provide power for, and control of, the siphon valves.

Suction Elbows

The pump intakes on Buena Vista, Wheeler Ridge, Wind Gap, Oso, and Pearblossom Pumping Plants are the elbow type, with a bend of 135 degrees. The intakes at Delta Pumping Plant and the smaller plants are the 90-degree elbow type and other conventional types.

The 135-degree intake was developed by the U.S. Bureau of Reclamation for the pumping plants on the San Luis Unit of the California Aqueduct (see U.S. Bureau of Reclamation, Hydraulic Branch Report No. Hyd-513). It offers minimum first cost by reducing excavation and concrete quantities. Operating costs also should be minimal because of the low head loss through the tube. Model tests have indicated that the tube produces a uniform velocity distribution at the eye of the pump, thereby helping the pump to operate more efficiently.

Neat lines of the suction tubes were developed by the Department for each pump. Specifications for the pumps allowed the manufacturer to modify these lines within certain limits (usually the second-stage concrete) to suit the pump. The concrete portions of the elbows were constructed by the building contractors while the steel portions were furnished and installed by the pump contractor. Each suction elbow is equipped with a man-door, a dewatering outlet, and fill and vent lines.

Intake and Draft-Tube Gates

Structural-steel bulkhead gates are provided for closure of the pump intakes and turbine draft tubes for all major plants to permit dewatering of a unit for inspection and maintenance. The size of the gates are dependent on the dimensions of the intake or draft tube. These gates are placed in the intake slots under no-flow conditions. Temporary storage of the gates is provided at the top of each gate slot. The gates generally are handled by gantry cranes or hoists mounted on monorails.

Figure 36. Siphon Outlet Valve—Wind Gap Pumping Plant

Electrical Features

General

Design of the electrical equipment and systems for power and pumping plants followed the traditional pattern for these types of installations. The major power equipment must be rugged and dependable. Control, protective, and metering systems must be fast, accurate, and dependable. All designs were established using the above criteria and considered safety, operation, maintenance, and established codes.

No single method of motor starting was found to be most suitable for all plants. Conditions of speed, horsepower, number of units, and economics influenced decisions at each plant. Descriptions of the various methods are contained in following chapters. The auxiliary systems intentionally were designed similarly to facilitate operation and maintenance.

One innovative concept was the use of a computer system for total control of power and pumping plants. The computer was designed for controlling, data logging, monitoring, and annunciating all plant operations at the plant control center and for certain control and monitoring at a remote area control center. These systems are described in Volume V of this bulletin. A local, manual, control system provides back-up to the computer system.

Computer programs were developed to assist in design work. These were used for grounding calculations, cable routing, conduit schedules, and termination schedules.

Electrical Standards and Codes

During preparation of designs and specifications, the Department made use of standards and codes developed by various organizations. These standards established a common and well-known guide for the quality of the equipment and systems sought. Test codes were especially important to establish procedures, tolerances, and required results. A list of organizations whose codes were utilized follows:

ASTM—American Society for Testing and Materials
AWS—American Welding Society
GO 95—General Order No. 95, Rules for Overhead Electrical Line Construction, State of California, Public Utilities Commission
IEEE—Institute of Electrical and Electronics Engineers
IPCEA—Insulated Power Cable Engineers Association
NEC—National Electrical Code
NEMA—National Electrical Manufacturer's Association
NESC—National Electrical Safety Code
UL—Underwriters' Laboratories, Inc.
ANSI—American National Standards Institute, Inc. (formerly USAS and ASA)

The Department also developed various informal standards for its own use. Some of the department standards which were used follow:

1. Switchboard mimic bus material and color coding.
2. Test facilities for differential relay circuits.
3. Wiring devices—This standard establishes the types of devices to be used for different applications and suitable company products.
4. Monitoring of circuit breaker trip coil.
5. Phase sequence and relations—This relates the phase sequence of motors, generators, and transformers to phase conductor positions in switchyards, switchgear, and bus connections.

It was the intent of the Department not to standardize on the product of one manufacturer for use throughout the Project. Such standardization would not have conformed with the intent of state law requiring competitive bidding. Two exceptions were made to this practice, both in the interest of convenience and safety of operations. A demand meter was selected to provide a record at the plants which was directly usable by the utilities. The test blocks and test switches for switchboards and switchgear were standardized for uniformity of use by the test technicians.

Selection of Major Equipment and Design Criteria

Power Transformers. The 17 power transformers located at Thermalito Powerplant and at Delta, Buena Vista, Wheeler Ridge, Wind Gap, and Pearblossom Pumping Plants have the following common characteristics. They are 3-phase, 60 Hz, type OA/FA (oil-immersed, self-cooled/forced-air-cooled) with a nominal 220-kV grounded-wye, high-voltage winding, and a nominal 13.2-kV delta secondary winding or windings. The selection of these 17 transformers will be discussed first, and then exceptions to this type of transformer at other plants will be considered.

The number of power transformers at each plant varies from two to seven. The number in a plant was determined by the size of the load and the motor starting method which was used. A minimum of two transformers was established so that a transformer outage of any kind would not make the entire plant inoperative. Less expensive switchgear is required when two smaller transformers are used. The following factors were considered in finally selecting a minimum of two transformers for each plant:

1. The reliability of plant operation is greatly increased by having more than two transformers, an advantage which is offset by the initial greater cost and added maintenance.

2. A study by a major power producer, on power plants representing 5,000 MW of power generation over 15 years, showed that modern transformers usu-

ally are highly reliable. No internal transformer faults had occurred, and external failures were confined to bushings and leakage of the cooling system. This indicated that additional transformers above the minimum of two need not be installed to gain reliability.

3. An arrangement of more than two transformers requires the installation of additional towers and switches in the transformer yard. Use of two transformers results in two lines connected directly to the transformers and terminating on the plant superstructure (Figure 37).

4. Two transformers at smaller plants allowed the installation to remain within the interrupting capacity limit of 15-kV metal-clad switchgear. One transformer necessitates air-blast, station-type breakers which increases the cost and maintenance for the breakers.

Transformer windings are connected grounded wye on the high-voltage side and delta on the low-voltage side. The selection of the wye-delta connection was based on the following:

1. The grounded neutral lowers the basic insulation level (BIL) requirement of the transformer, resulting in a less expensive unit.

2. A BIL of 825 kV for the transformer was considered to be consistent with the current industry trend toward lower BIL. Present-day equipment, such as fast-tripping circuit breakers and improved lightning arresters, makes the use of lower BIL possible. However, to be conservative in design, the transformers selected have a BIL rating of 900 kV.

3. Protective relaying on the grounded neutral protects the transformer by detecting ground faults in the 220-kV system.

4. Wye-wye or delta-delta connections are undesirable because of third harmonic voltages occurring, which would cause stress on winding insulation.

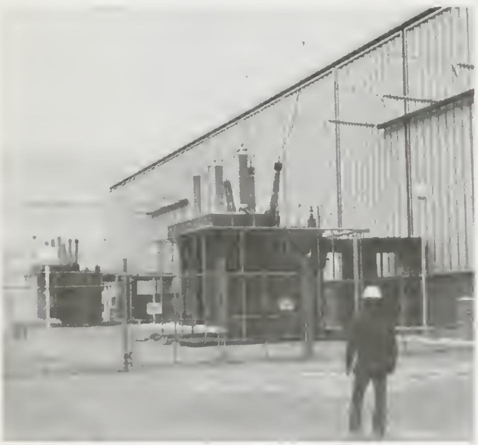


Figure 37. 42.75/61.0-MVA Transformer—Buena Vista Pumping Plant

Each transformer has a no-load tap changer in the high-voltage windings to adjust for deviation from nominal line voltage of 220 kV.

Three types of transformer cooling were considered: OA (oil-immersed, self-cooled), OA/FA (oil-immersed, self-cooled/forced-air-cooled), and FOA (forced-oil and forced-air-cooled). A comparative economic study was made of these three types of cooling using a 35-year life and present value based on a 4% interest rate. Type OA/FA cooling was selected after considering the following factors:

1. High initial cost and low operating cost of OA-type transformers over a 35-year period showed the total cost to be greater than the OA/FA and FOA transformers. Also, because of the greater size and weight involved, a larger and stronger foundation would be required.

2. The study indicated negligible cost difference between OA/FA and FOA transformers over 35 years. Although initial cost of FOA would have been less than the OA/FA type, cost of power required for auxiliary equipment on the FOA type would have exceeded that for the OA/FA type. Beyond the 35-year period, the OA/FA type would be more economical to operate.

3. Maintenance on the FOA-type transformer would be more frequent than that for the OA/FA type because of oil pumps.

4. The dual rating of the OA/FA type adapted to the number of motors connected. When one or more motors were not operated, fan-cooling equipment would not be required.

The transformers at the remaining plants are identical in characteristics to the transformers discussed previously with the following exceptions:

1. The transformers at Hyatt Powerplant are type FOW (oil-immersed, forced-oil-cooled, forced-water-cooled). These transformers are located in the underground powerhouse, and type FOW cooling is the most efficient method of removing heat and results in a transformer of minimum physical size and space costs.

2. Transformers for San Luis Pumping-Generating Plant and Dos Amigos Pumping Plant are identical and were purchased in a single contract by the U. S. Bureau of Reclamation. They were specified with three cooling ratings due to the varying load caused by reservoir level, and three classes of cooling were acceptable; that is, OA/FA/FA, OA/FOA/FOA, and OA/FA/FOA. The contractor chose to furnish OA/FA/FOA.

3. Transformers at A. D. Edmonston Pumping Plant are type OA and were selected to conform to the more conservative design of this large plant.

4. Transformers at Oso Pumping Plant have a 67.5-kV high-voltage winding for the available utility service. The low-voltage winding has a half-voltage tap to start the large motors at reduced voltage (Figure 38).

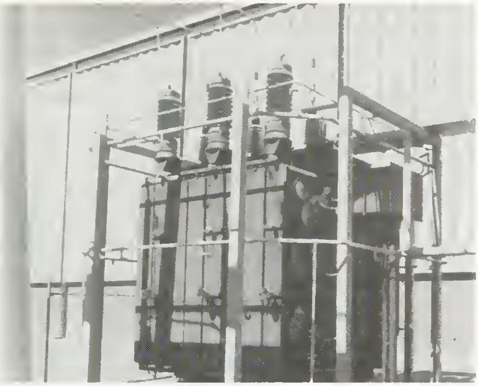


Figure 38. 28.5/38.0-MVA Transformer—Oso Pumping Plant

5. The transformers at Devil Canyon Powerplant have a 115-kV high-voltage winding to match the existing transmission line voltage.

Selection of transformers for the smaller pumping plants (Las Perillas, Badger Hill, North Bay Interim, South Bay, and Del Valle) is covered in the individual chapters on these plants.

Spare Power Transformer. A spare transformer was purchased for Edward Hyatt Powerplant with a rating of 128 MVA and either FOA or FOW cooling systems. This transformer can be used to replace the largest transformers on the Project, which are at Edward Hyatt Powerplant and A. D. Edmonston Pumping Plant. It also can be used as a spare at all major plants on the Project except Devil Canyon, Delta, and Oso.

Using the spare at Delta Pumping Plant would cause the interrupting capacity of the switchgear to be exceeded, and the spare does not match the voltage used at Oso and Devil Canyon. A spare transformer is not considered essential at these three plants since they have storage reservoirs to provide back-up water service.

Generators and Motor-Generators. The electrical and mechanical designs of the generators and motor-generators were selected to match requirements of the utility power systems and the hydraulic conditions of the plants. Standard designs were specified wherever possible to minimize costs.

Class B insulation which permits a 60 degree Celsius temperature rise rating to match the turbine or pump-turbine power at rated head was specified as standard. Class B insulation also permits a 15% overload without exceeding a permissible 80 degree Celsius temperature rise. Terminal voltages specified were primarily based on manufacturer's recommendations. Rated motor voltage of motor-generators is 5% less than the rated generator voltage to allow for the system voltage drop. Each generator and motor-generator has a direct connected exciter.

Motors. Several features and design considerations for motors are common to the major pumping plants of the Project. The selected design provides an air housing, direct-connected exciters, one thrust and two guide bearings, and a conservative temperature rating.

All large motors have one guide bearing and one thrust bearing above the rotor and a second guide bearing below the rotor. Two guide bearings were specified to achieve maximum stability during reverse runaway speed and possible earthquake motion. Most of the motors have a relatively high speed for vertical machines. The thrust bearing was located above the rotor mainly to simplify the building design and allow construction of the building to start prior to design of the motor. Headroom requirements were greater; however, structural configuration below the motor was simplified. Space below the motor floor was reduced since the bearing would be lifted upward rather than lowered and moved horizontally at a lower plant elevation. Thrust-bearing high-pressure oil pumps were installed in the thrust bearing to lift the rotor prior to starting and assist in lubrication, both during starting and stopping. The off-peak pumping schedule of the units made this precaution necessary to ensure the longest possible life of the thrust bearing. The motor also can start and stop without use of the lift pump, if the need arises.

Class B insulation with a temperature rating of 80 degrees Celsius was required although the actual rise was limited to 60 degrees Celsius for rated operating conditions. In effect, this requirement provides an overload capability of about 15% if the pump requires more horsepower than the pump model tests indicated. Also, voltage fluctuations may cause a change from rated conditions, and a longer motor life can be expected if the rise does not exceed 60 degrees Celsius.

Direct-connected exciters were selected rather than unit static exciters, primarily for reliability. Direct-connected exciters have proven to be satisfactory over many years of operating experience (Figure 39). Static exciters had limited operating experience, and their

Figure 39. Generator and Motor-Generator Exciters—Edward Hyatt Powerplant

Figure 40. 44,000-Horsepower Synchronous Motors—Wind Gap Pumping Plant

Figure 41. 11,250-Horsepower Synchronous Motors—Delta Pumping Plant

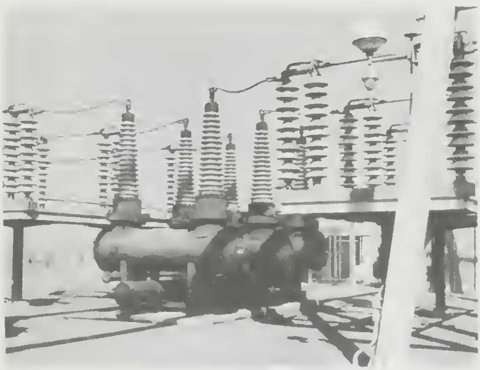


Figure 42. 230-kV SF_6 Circuit Breaker—Delta Pumping Plant

use was even more indeterminable for motors of the sizes required. A single, separate, excitation system for all motors in a plant was considered. These units could have been higher speed and much lower in cost. The single system was rejected under reliability considerations.

Enclosures, either concrete or steel, were provided for use in cooling and protection of the motors. The motor heat loss is absorbed in air-to-water heat exchangers inside the enclosures to assure uniform motor temperatures. An extensive cooling system for the building is not necessary if motor heat is eliminated without release into the building. Motor enclosures made it possible to provide CO_2 for protection in event of fire in the motor (Figures 40 and 41).

Power Circuit Breakers. Breakers for use in the 230-kV switchyards are rated at 20,000-MVA interrupting capacity in three cycles. This was the highest capacity available at the time of procurement and provided for future system growth. This selection was made regardless of a lesser need, since the cost increase over lower capacity breakers was too little to influence the choice. Higher voltage transmission systems with higher capacity requirements can be expected in the future. These future interconnections probably would dictate replacement of lower capacity breakers had they been selected.

Oil and oil-less circuit breakers were evaluated (Figures 42 and 43). The decision to use oil-less breakers was based on an engineering and economic evaluation which, because of the lighter breaker weight, included reductions in cost for annual maintenance, foundation (approximately 70% less), and installation. Oil-handling and fire-protection equipment were not required, permitting even further cost savings.

High-Voltage Systems. The high-voltage system includes all equipment operating at transmission-line voltage at each plant. All equipment is in a fenced yard. At Edward Hyatt Powerplant, the power transformers are located in the powerhouse, and the connections from the switchyard to the transformers are made underground using 230-kV pipe-type cable. Connections at all other plants utilize overhead conductors.

Figure 43. 230-kV Air-Blast Circuit Breaker—Pearblossom Pumping Plant

Switchyards were located as near the plant structure as permitted by the plant site to minimize control cable lengths and for convenience of operation (Figure 44). At all major pumping plants, switchyards were located outside of the bowl excavation for the plant to save excavation costs. Transformers were located close to the plant structure to minimize low-voltage bus or cable runs (Figure 45). They were located in the switchyard for smaller plants, where both switching equipment and transformers could be adjacent to the plant structure.

High-voltage switching arrangements were selected after consideration of the flexibility and protection required at each plant. The number of utility lines and their reliability were also a factor. Equipment in the switchyard consists of power circuit breakers, disconnecting switches, lightning arresters, and instrument transformers. Operating voltages were determined primarily by load requirements. Transmission lines were constructed by the utilities to provide a voltage level consistent with the load. Electrical insulation levels and protective equipment were coordinated to provide safe margins of insulation strength over the maximum voltages permitted by protective devices.

Local Control Systems. In addition to the supervisory control systems described in Volume V of this bulletin, there is a local control system for each plant. Local systems are interfaced with supervisory systems for remote control and monitoring, or monitoring only, of each plant (Figure 46). In conjunction with supervisory systems, local systems were designed for minimum operator attendance at the plants.

The control system includes equipment to permit plant operators to control and supervise operation of the motors or generators and the plant auxiliaries. This consists primarily of indicating and recording instruments, control switches, protective relays, and annunciators. In the larger plants, equipment is mounted on switchboard panels, while in smaller pumping plants the equipment is mounted on panels in the motor switchgear. Equipment is arranged on the panels to provide maximum convenience and accuracy for manual operations and maintenance (Figures 47 and 48).

Figure 44. 230-kV Switchyard—Wheeler Ridge Pumping Plant

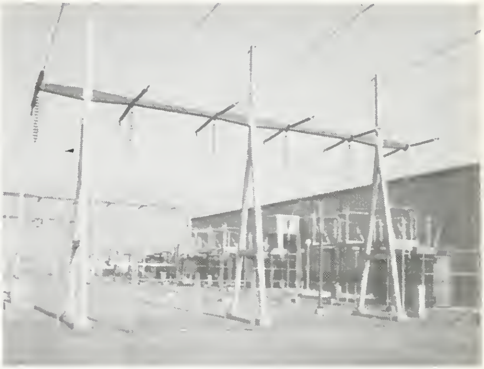


Figure 45. Transformer Yard—Wind Gap Pumping Plant

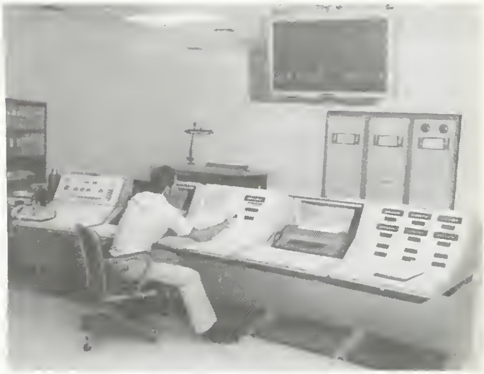


Figure 46. Plant Control Console and Mimic Display—Wind Gap Pumping Plant

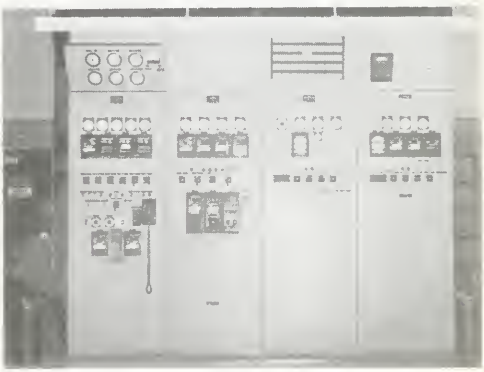


Figure 47. Unit Control Board—Delta Pumping Plant

Figure 48. Governor Control Cabinet—Devil Canyon Powerplant

Figure 49. Transformer Yard—A. D. Edmonston Pumping Plant

Figure 50. Surge Protection Cubicle—Devil Canyon Powerplant

Earthquake Requirements

Design requirements of electrical equipment and systems considered earthquake hazards and provided a different degree of protection according to the area. In specifying the forces to be withstood by the equipment, available equipment had to be considered. Nothing could be gained by specifying equipment which could not be furnished by the industry.

The switchyards for Edward Hyatt and Thermalito Powerplants and Delta Pumping Plant have rigid bus. These plants are not in areas of high seismicity. Cost and aesthetics were the governing factors in designing these yards. All other major plants in the Project are in areas of higher seismicity, and the switchyards have strain bus to withstand ground motion.

Equipment originally was specified to withstand a horizontal acceleration factor of 0.2g. This was the maximum value that had been considered by most equipment manufacturers. All equipment, including power transformers, was to be anchored or braced. Recent research and development programs by the industry have caused the criteria to become more severe. Also, recent earthquakes in Southern California affecting other projects have resulted in more knowledge of the forces involved. As a result, the Department has changed its specifications by requiring electrical equipment to withstand seismic forces as follows:

> Motors, generators, and exciters: Apply 1.0 times the weight of the equipment in any direction.
>
> Cabinets and accessories therein: Apply 0.75 times the weight of the equipment in the horizontal direction and 0.50 in the vertical direction.

In addition to the more severe requirements imposed upon equipment manufacturers, the Department has given more attention to supporting structures. Equipment, such as lightning arresters and instrument transformers in the high-voltage ranges, requires a supporting pedestal to dampen forces in the critical frequencies. The Department is presently modifying supports for circuit breakers and anchoring and bracing cabinets, tanks and similar equipment.

Common Systems and Equipment

Motor and Generator Voltage Systems. These systems include equipment between the motor or generator terminals and the power transformer. In addition to motor or generator leads, the equipment includes switchgear, instrument transformers, surge protection equipment, and neutral grounding equipment.

Metal-enclosed rigid-bus-type leads are used for the required current capacity for all generators and for larger motors (Figure 49). Insulated cable was used for leads of the smaller motors. Switchgear selected for use at all plants is the metal-enclosed type for reliability, safety, and standardization. Switchgear was placed indoors at all plants, except Thermalito and Devil Canyon where suitable space was not available.

Surge protection equipment generally consists of a metal-enclosed assembly of lightning arresters and capacitors to provide protection for the motor or generator windings against high-voltage surges. Generators and larger motors have individual surge protection (Figure 50). In smaller pumping plants, surge protection is for a group of motors. Primarily to limit overvoltages and for ground fault relay protection, neutrals of the generators and larger motors are grounded. The method used in the major plants incorporates a distribution transformer with the high-voltage winding in series with the machine grounded neutral and a resistor across the low-voltage winding. Solid neutral grounding is used on smaller motors that are wye-connected.

Direct-Current Systems. A 125-volt, direct-current, battery system was installed at all plants, except Del Valle, South Bay, North Bay Interim, Las Perillas, and Badger Hill where stored-energy and alternating-current systems are adequate. These systems provide a reliable power source for control of circuit breakers and protective relays and a minimum of two hours of emergency lighting when there is a failure of the normal alternating-current system.

Each system consists of 60 lead-acid cells, two chargers, and a direct-current distribution panel. During normal operation, one charger will supply continuous direct-current load of the plant, and the battery will float on the bus and supply momentary large loads. The second charger is used as a standby for the plant charger or for both the plant and control-system chargers (Figures 51 and 52).

Four types of battery construction were evaluated during design of the system. These were nickel-cadmium and nickel-iron with an alkaline electrolyte, and lead-calcium and lead-antimony with an acid electrolyte. Manufacturers of alkaline batteries claim a longer life and reduced maintenance for this type of battery. This is offset by higher initial cost and the inability to maintain full capacity on the voltage used for float charging. The lead-calcium battery was rejected due to its undesirable slow charging rate as it nears final charge. A lead-antimony cell was selected on the basis of its lower overall cost and long history of reliable service.

The capacity per cell was determined by the most severe duty cycle the system could reasonably be expected to experience. For example, at one plant this cycle was assumed to consist of closing a 230-kV breaker, starting a main motor at five-minute intervals, opening the 230-kV breaker due to a fault, supplying emergency lighting for two hours, and reclosing the 230-kV breaker.

Station Service System. Two powerplants (San Luis and Devil Canyon) and all pumping plants on the main Aqueduct (Delta, Dos Amigos, Buena Vista,

Figure 51. 125-VDC Battery Room—Buena Vista Pumping Plant

Figure 52. 125-VDC Battery Chargers—Delta Pumping Plant

Figure 53. Cable Tray Gallery—Oso Pumping Plant

Wheeler Ridge, Wind Gap, A. D. Edmonston, and Pearblossom) and Oso on the West Branch have a station service system of similar design. The system consists of two substation transformers; a 480-volt secondary bus with two main breakers and a tie breaker installed between the transformers; and load breakers which feed motor, lighting, and air-conditioning distribution centers located throughout the plant (Figure 53). One distribution center in the service bay has an emergency bus supplied by a small engine-generator for critical loads such as drainage and dewatering valves, sump pump, elevator, battery charger, and roll-up doors in the service bay.

Alternative independent sources of power are considered necessary to ensure maximum station service availability. No utility lines were available in the plant areas except the high-voltage lines serving the plant, so alternative power supplies were limited to those within the plant. The most flexible system was a double-ended substation fed from each of two power transformers, with each transformer having a separate transmission line if available. This arrangement supplies station service to the plant whenever power is available in the switchyard and one power transformer is operable.

Each of the two substation transformers is self-cooled/forced-air-cooled, dry type with a nominal 13.8-kV primary winding and 480-volt secondary winding. Dual-rating allows the basic transformer for normal loads and the forced-air rating for overloads or possible future loading. Since substations were located inside the plants, dry-type transformers were selected to eliminate need for vaults, oil traps, and maintenance required by a liquid coolant.

A relay in the neutral ground of each transformer is used to annunciate a ground fault at the station service annunciator, on the plant display, and in the control room. This relay doesn't trip the 13.2-kV circuit breaker in the switchgear or the 480-volt station service main circuit breaker. A large ground fault will cause an overcurrent in the feeder circuit and trip the feeder breaker.

The demand load on each half of the station service substation is approximately 80% of the transformer self-cooled rating. This allows one transformer at the fan-cooled rating to supply the entire station service load unless the heating and ventilating feeders are at maximum demand. This was considered so unlikely that automatic shedding of these loads was not provided. However, if loads are added to the substation in the future, it will be necessary to shed loads automatically when the transformer temperature relay indicates an overload. Shunt trips on the heating and ventilating breakers are provided for this purpose.

The two main secondary circuit breakers and the tie circuit breaker of the substation are electrically interlocked to prevent more than two of the three from being closed at the same time. If one side of the substation is disconnected for any reason except a fault on the 480-volt bus, the tie breaker automatically closes and the entire station service load is carried by the other side. With this switching, downtime on plant facilities is kept to a minimum. In event of a fault on the 480-volt bus, the main secondary breaker opens to isolate the fault, the 13.2-kV breaker remains closed, and alarm contacts on the secondary breaker operate a relay to prevent the tie breaker from closing on the fault.

Distribution centers for motors, lighting, heating, and ventilating are located throughout the plant near the center of loads which they supply (Figure 54). Centers supplying the pumping unit auxiliaries, such as cooling water and oil pumps, were considered to be sufficiently critical to warrant alternate supplies to them from the substation. A set of feeder cables from each side of the substation split bus supplies one of two main breakers in these distribution centers.

The need for an alternating-current emergency system was based on the possibility of a prolonged power outage. Without an engine-generator set available, it would be possible to flood the drainage sump, fully discharge the storage batteries, and strand the elevators between floors. The emergency generator is connected through the battery charger to assist the direct-current system. It was not intended that emergency lighting be included in the generator capacity.

Five smaller pumping plants (North Bay Interim, South Bay, Del Valle, Las Perillas, and Badger Hill) located on branch aqueducts or storage facilities have smaller and less critical plant loads and correspondingly simpler station service systems. South Bay Pumping Plant has two utility-owned transformers,

Figure 54. 480-Volt Distribution Center—A.D. Edmonston Pumping Plant

and the station service consists of a double-ended substation without any emergency generator, and the distribution centers are grouped near the substation in each end of the plant. The remaining four smaller plants have a station service system consisting of a single transformer and main breaker supplying a distribution center.

The station service system at Thermalito and Edward Hyatt Powerplants are described in their respective chapters.

Lighting Systems. Lighting systems at all the large plants were designed in accordance with the general considerations described herein. One significant exception is the high-bay lighting at Edward Hyatt Powerplant, where fluorescent fixtures were used (instead of mercury-vapor) to enhance the special architectural treatment of the underground plant (Figure 55).

Lighting systems consist of three separate voltage supplies: a 480Y/277-volt system for mercury-vapor lights in the high-bay and outdoor areas, a 208Y/120-volt system for the lighting in the remainder of the plant and switchyard, and a 125-volt emergency lighting system.

Three types of lamps are used throughout the plants and their exterior: (1) mercury-vapor, (2) fluorescent, and (3) incandescent.

Mercury-vapor lamps were chosen for high-bay areas because of their high lumen output and long life. The 400-watt lamps are rated at an average of 18,000 lumens over a life of 16,000 hours. These lamps also maintain a very high efficiency.

Figure 55. High-Bay Fluorescent Lighting—Edward Hyatt Powerplant

Fluorescent lamps were chosen for low-bay areas because of their high efficiency and output and because the illumination requirement for the low-bay areas is greater than 30 foot-candles. At this illumination level, a better quality of lighting is achieved with fluorescent lamps than incandescent lamps. The lamps are most suitable for installations requiring a low brightness for visual comfort. In low-bay areas, the brightness contrast of the lamp and surroundings becomes increasingly important.

Incandescent lamps are used in areas requiring only a low illumination level (10 to 20 foot-candles), such as machine housings and coupling galleries where lights are used infrequently. They also are used for direct-current emergency lighting and decorative lighting. Repeated switching of incandescent lamps will not lower their life expectancy as it will for fluorescent and mercury-vapor lamps.

Initial cost of incandescent systems is less than that of fluorescent systems but, because of their higher efficiency, fluorescent lamps are more economical to operate. Therefore, the greater number of operating hours per year and the higher the power rate, the lower will be the overall cost of fluorescent systems compared to incandescent systems.

Types of fixtures were selected on the basis of their efficiency of reflection and distribution. Another consideration was the appearance with respect to architectural considerations in the area in which it is used.

A fixture with narrow lumen distribution was required in high-bay areas because of the high mounting height (approximately 45 feet). Low brightness was not required in the high-bay areas since they are outside of the normal cone of vision. Ventilating holes in the reflectors of the fixtures cool and prolong the life of the mercury-vapor lamps.

Vaportight fixtures were installed in battery rooms, oil storage rooms, and chemical storage rooms. These fixtures will resist moisture, vapors, and dust. They also will prevent the escape of sparks into the rooms.

Because frequent switching of mercury-vapor and fluorescent lamps reduces their life expectancy, most of these fixtures are to be operated continuously. They are controlled only from lighting panelboards. Wall-mounted switches are provided for the lighting circuits in machine enclosures, coupling galleries, and various rooms in the service bays.

Fluorescent fixtures in the plant control room are controlled by a dimmer system. The illumination level in a room can be controlled to various levels allowing selection of maximum comfort and most suitable contrast between plant displays and surroundings.

All plant exterior, roadway, switchyard, and transformer yard lighting is controlled photoelectrically. Lights are turned on or off depending on the intensity of the sun's illumination. Auxiliary lighting for the disconnect switches in the switchyard is manually controlled. These circuits will be utilized only when the switches are operated at night.

The purpose of the 125-VDC emergency lighting system is to ensure minimum-intensity illumination for the most vital plant areas, such as the control room, in event of failure of the regular alternating-current systems. Emergency lighting fixtures are located throughout the plants to assist personnel in leaving the buildings. It was not intended to install a system which could be used for maintenance or operation after the alternating-current system failed.

Grounding System. A grounding system for each plant provides a low resistance to ground, assures safety of personnel and equipment during fault conditions, and facilitates fast relay action.

All plants except the smaller ones, such as North Bay Interim, have a similar grounding system. The system consists of interconnected grids of 500-MCM copper cable buried under the plant, transformer or bus yard, and switchyard. These grids are connected by risers to intermediate grounding grids at each elevation within the plant. All equipment enclosures, electrical system neutrals, and exposed metalwork, such as frames and railings, are grounded to these intermediate grids. Plant and transformer grids are directly connected and have two 500-MCM cables connecting these grids to the switchyard grid at each plant. The grids are interconnected through test stations in the switchyard and in the plant, which allows grids to be isolated for ground resistance tests.

Most information required to design the grounding system was taken from IEEE Publication No. 80, "Guide for Safety in Alternating-Current Substation Grounding", March 1961. The prime consideration throughout design was safety of personnel and equipment. Other governing factors were:

1. Magnitude of the ground-fault current
2. Soil resistivity
3. Tolerable touch, step, and transfer potentials
4. Configuration of grounding grids

The calculation of ground-fault current was based on the short-circuit capacity of the utility lines serving the plants plus plant contributions. For 230-kV lines, the expected duty in 1980 is 15,000 MVA, which gives an asymmetrical fault current of 14,200 amperes. A conservative design value of 20,000 amperes was used.

Resistance of the grounding systems was assumed initially to be 0.2 ohm between points of measurement in a plant and a remote location adjacent to the Aqueduct. In grounding calculations, an initial design value must be assumed, and 0.2 ohm was considered a conservative value.

The soil resistivity was measured at plant sites during foundation testing and ranged from 6 to 60 ohm-meters. The various grids were designed to have calculated resistances of approximately 0.25 ohm. The measured grid resistances have been equal to or less than this value.

A low-resistance grounding system is not necessarily a safe one. To verify safety of the systems, calculations were made to determine the tolerable potentials, which are step, touch, and transferred voltages.

Step potential is a potential that would be measured over a distance approximately equal to a person's step. It is the voltage experienced by a person walking in a switchyard during an electric fault to ground. Touch voltage is the distance between the feet and the point of contact of grounded equipment. Transferred voltage is between the points where the person is in contact with equipment and the remote grounding point of the equipment. Mesh voltage, a special case of touch voltage, is between the buried ground conductors and the ground surface at the center of the grid mesh.

During a ground-fault condition, the potential of the grounding grids and all equipment connected to them increases sharply above ground potential. For safety, a person should be at the same voltage as the equipment with which he is in contact.

The worst location during a fault was assumed to be in the switchyard. The plant would be relatively safe because fault current would be restricted by the transformer impedance. In calculating these potential differences, duration of the fault was assumed to be 0.5 second and surface resistivity of wet crushed rock in the switchyard of 3,000 ohm-meters.

The IEEE Publication No. 80 states that mesh potential is the maximum potential within the grid and is larger than the step and touch potentials. Therefore, grids were designed so mesh potential was less than tolerable potentials. As an example, at some plants the calculated tolerable potentials for step, touch, and mesh voltages were 10^6 volts, 354,000 volts, and 10^4 volts, respectively. The anticipated mesh potential was 300 volts, well within the tolerable limits.

The grounding grid configuration is a key factor in ensuring safety and a low ground resistance. The overall resistance of a grid is proportional to the amount of copper buried in the ground. The configuration in which the cable is laid determines the safe tolerable potentials of a grid. The 500-MCM copper cable for the grid was chosen on the basis of the expected ground-fault current and for its mechanical strength. Cable was laid in trenches relatively close together to reduce the steepness of the induced voltage during a fault. The grid consists of many cross connections to ensure electrical continuity in event of cable breakages.

The ground test stations in the plant and the switchyard are for the purpose of isolating their respective grounding grid for periodic testing of ground resistance. The plant test station isolates plant equipment from the plant, transformer yard, and switchyard ground grids. The switchyard test station isolates the switchyard grid and equipment from the plant and transformer yard grids. No test station isolates the transformer yard grid from the plant grid, because both grids were designed as one to achieve the desired ground resistance

Each overhead ground wire protecting the 220-kV lines has an insulator to isolate the switchyard ground grid from the plant grid when the switchyard is being tested. In this arrangement, the plant grid need not be isolated from grounded plant equipment, which includes overhead wires, to test the switchyard grid.

For cathodic protection, steel and copper should be separated where possible since steel will sacrifice to copper, resulting in damage to the steel. Where the two types of metals can be separated, a reduced-capacity cathodic protection system can be installed. It was possible to separate the plant-grid system from plant steel by physical separation, except for risers from the grid. These risers were insulated with Type RHW insulation and connected into the ground testing station. The ground testing station also serves as a cathodic protection station.

It was not reasonable to separate the switchyard grid from switchyard steel because of the great number of risers required to connect the switchyard steel. Grounding connections to the steel are exposed for inspection and can be reattached if conditions warrant.

In addition to establishing a cathodic protection system for the plant steel, steel and copper were separated where concrete-embedded moist conditions occur. Cables for the intermediate grids and risers within the plant, which mainly were installed in exterior walls, were also installed with Type RHW insulation. This allowed attaching the grounding conductor to reinforcing steel without possible deterioration of the steel. No attempt was made, however, to separate steel and copper for individual connections where only equipment, frames, railing, or ladders were involved.

Communication Systems. Plant communications at the larger plants are composed of two systems: a code-call system for paging personnel, and a sound-powered telephone system for coordinating unit start-up and maintenance operations.

Code-call systems consist of a coded signal generator with a capacity of 20 or more calls in the control room and signal devices (horns or bells) located throughout the plant and in the switchyard, transformer yard, and forebay areas. Personnel working at the plant are assigned one- or two-digit numbers for paging. When operated, the signal generator will sound four rounds of long codes or eight rounds of short codes, or will page continuously, depending on the position of a selector switch.

The sound-powered telephone system functions as a common talking system at some plants or as a common talking-selective signaling system with a master station permanently installed in the control room console at other plants. Head-chest nonringing sets for either type system can be plugged into jacks located throughout the plant. The common talking system has a common bus throughout the plant. This allows common talking between any two or more stations at any location on the systems. The common talking-selective signaling system has portable master stations in addition to nonringing sets. Selective ringing is possible between the control room and any plant station and vice versa. Selective ringing also is possible between stations at associated pieces of operating equipment. For instance, the station at a unit switchgear can ring the pump alcove, motor air housing, and valve room of the same unit and also can ring the switchyard, siphon breaker house, transformer area, automatic equipment room, and control room.

A commercial telephone installation and a private automatic switchboard system were compared with the sound-powered system. The sound-powered system was selected because of its relatively low cost, reliability, and adaptability to rugged use in both construction and operating environment.

Protective Relaying. Protective relays of various types protect major items of equipment and transmission systems in accordance with current utility and industry practices. Conventional, overlapped, zone protection is provided for motors or generators, power transformers, 220-kV buses, and 13.2-kV buses. Relays either activate an alarm and/or initiate a shutdown of affected equipment (Figure 56).

In general, certain relay types are utilized for primary protection, and additional relays are used for back-up protection. Large motors and generators, as an example, primarily are protected against electrical faults by differential and ground-fault relays with overcurrent relays as back-up protection. Primary protection against overheating is by temperature sensors embedded in the bearings or winding metal, with secondary protection consisting of temperature sensors in the bearing oil, motor cooling air outlets, and cooling water.

The final concept in protective relaying schemes resulted in two types of shutdowns:

1. Abnormal operating conditions which initiate an emergency shutdown, in which the motor or generator breaker is opened immediately and the main valve starts closing simultaneously.
2. Abnormal operating conditions which initiate a normal shutdown, in which the main valve is closed and the motor or generator breaker is opened.

Emergency shutdowns are initiated by relays which sense conditions of a serious nature and trip the circuit breaker. With this type of shutdown, the responsibility for decision-making is withheld from the operator. The unit is tripped directly or through auxiliary relays, and the operator cannot abort the shutdown.

Normal shutdowns are initiated by those relays which do not initiate a breaker trip. The control system receives an alarm input and alerts the plant operator. For these alarms, classified as secondary in nature, the operator is given time to make a decision on the matter of shutdown. The operator has the option of initiating a shutdown or allowing the unit to operate. If the unit continues operating and the condition re-

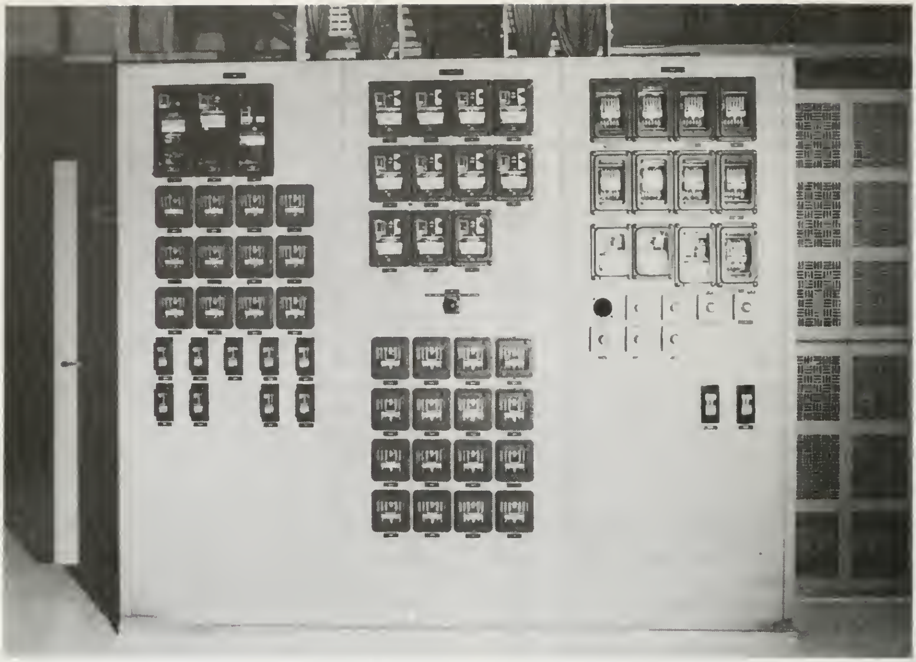


Figure 56. Protective Relay Board—A. D. Edmonston Pumping Plant

mains stable, no further action is taken by the control system. If the abnormal condition worsens and reaches a preset upper limit, the control system automatically initiates a normal shutdown routine.

In practically all cases, auxiliary relays are required because primary relays have an insufficient number of contacts or ampere capacity for all the functions required for annunciator alarm, breaker trip, control system input, and so forth.

Metering. Metering was installed throughout the plants to assist in operation, maintenance, and determination of power use.

A contract for power and transmission service was prepared, dated November 18, 1966, and titled "Contract between California Suppliers and the State of California for the Sale, Exchange and Transmission of Electric Capacity and Energy for the Operation of State Water Project Pumping Plants". The contract was executed by Pacific Gas and Electric Company, Southern California Edison Company, San Diego Gas and Electric Company, and the Department of Water and Power of the City of Los Angeles, referred to as the "Suppliers", and the State of California, Department of Water Resources. The contract did not give specific metering requirements but did establish that agreement must be reached on metering equipment and installation.

Revenue metering equipment is furnished and maintained by the Department of Water Resources except the metering for Thermalito and Edward Hyatt Powerplants which is installed at Table Mountain Substation and is maintained by the Pacific Gas and Electric Company. The suppliers preferred that revenue metering be installed on the line side of the department-owned power transformers. This is a more expensive installation than metering at the transformer secondary voltage but was installed at most locations. However, at Buena Vista, Wheeler Ridge, and Pearblossom Pumping Plants, it was agreed to install revenue metering on the transformer secondary side with load compensators to add transformer losses to the meter load (Figure 57).

The revenue metering consists of watt-hour meters for each utility bus to transmit unit power pulses to a magnetic tape recording demand meter. At pumped-storage plants, both incoming and outgoing power are metered.

At unit switchboards, voltage regulators, and station service substations, all of the parameters essential for local operation are displayed on indicating meters.

Since the control system continuously monitors all plant parameters and annunciates alarm conditions, no indicating meters are provided for operating in the plant control room under normal conditions. For maintenance or unusual operating conditions, approximately eight digital displays and the same number of trend recorders are at each plant control room. Any analog input to the control system can be connected to these displays and recorders.

Construction

Contracts for the construction of the power and pumping plants for the State Water Project, including the furnishing and installing of pumps, turbines, motors, generators, and associated equipment, were awarded and administered in accordance with the provisions of the State Contract Act, Sections 14250 to 14424 of the Government Code of the Statutes of the State of California. The State Contract Act requires that bids be solicited in writing and that the contract be awarded to the lowest responsible bidder. To comply with the Act, the following procedures were employed:

1. Prequalification of prospective contractors—A two-phase prequalification procedure for screening contractors desiring to bid was used to establish qualified bidder lists. First, if the required financial statement indicated that the contractor had the necessary resources, the request for prequalification was further processed. Secondly, the contractor's ability based on the firm's overall experience and other uniform factors was assessed.

For contracts involving the design, manufacture, and installation of major equipment, a department team, when necessary, was assigned to inspect and report on the prospective contractors' manufacturing facilities to assist in the prequalification process.

2. Advertisement and Award of Contracts—Public notice of a project was given once a week for at least two consecutive weeks in a newspaper published in the county in which the project was located and in a trade paper of general circulation in either San Francisco or Los Angeles, as appropriate. A "Notice to Contractors", in each case, was sent to all contractors on the list of qualified bidders. This document generally described the requirements and extent of the work and indicated the time and place for receiving bids.

Contracts were awarded to the lowest responsible bidder. Responsible bids were those meeting all the conditions of bidding stated in the bidding requirements and determined to be reasonable in cost when compared with the engineer's estimate.

Figure 57. Utility Metering Equipment—Wheeler Ridge Pumping Plant

In addition to work performed under the terms of the State Contract Act, electrical and mechanical equipment associated with the construction of the power and pumping facilities were purchased through the State Department of General Services, Office of Procurement, in accordance with Section 14780 of the Government Code.

The Department of Water Resources' organization for supervision of construction activities consisted of project offices at selected locations throughout the State and a headquarters construction office located in Sacramento (Figure 58). Each project office was responsible for all project construction work within a particular geographical area and was staffed with construction engineers, inspectors, engineering geologists, and laboratory and other technicians. The headquarters construction staff provided administrative and liaison services to the project offices and, through an equipment and materials section, assisted with the factory inspection of materials and equipment to be incorporated in the work. This equipment and materials section also inspected major equipment components at their source of manufacture, including equipment furnished by contract through the Department of General Services.

Construction practices and procedures are detailed in the Department's Construction Manual.

Figure 58. Location of Construction Project Offices

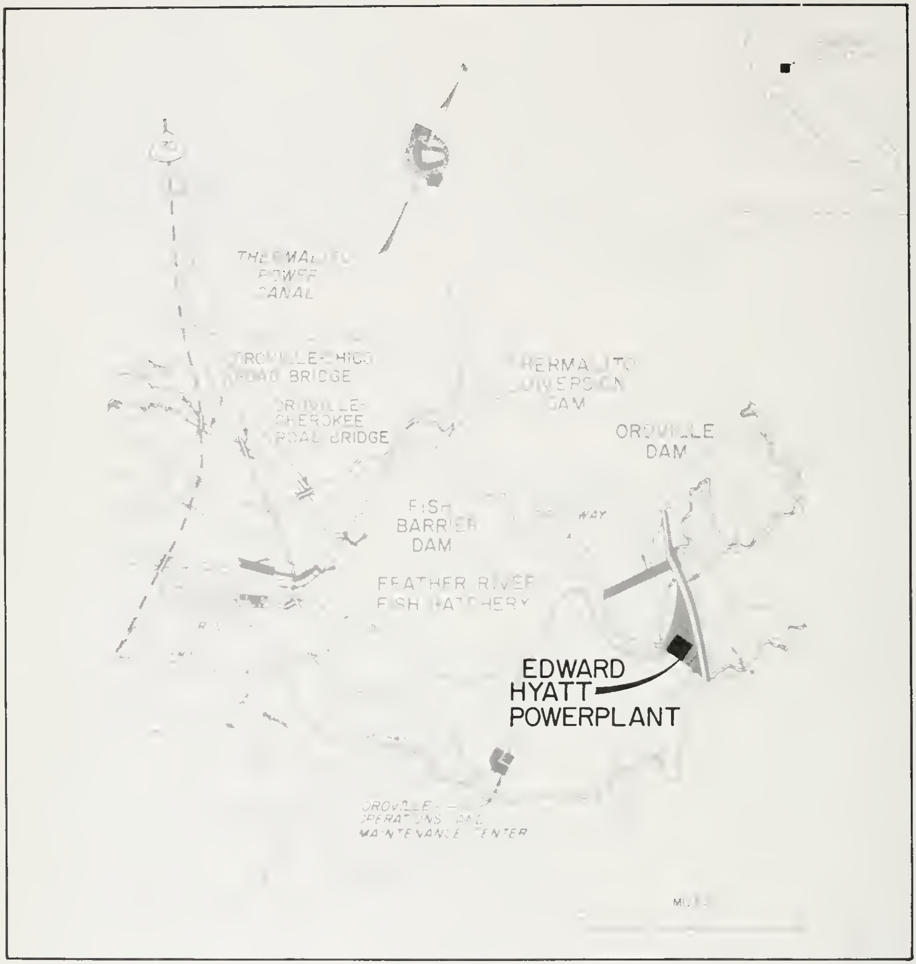


Figure 59. Location Map—Edward Hyatt Powerplant

CHAPTER II. EDWARD HYATT POWERPLANT

General

Location

Edward Hyatt Powerplant (formerly called Oroville Powerplant) is an underground, hydroelectric, pumping-generating facility located on the Feather River approximately 5 miles northeast of the City of Oroville, Butte County. Powerhouse and appurtenant features are located in rock in the left abutment near the axis of Oroville Dam. Construction of the plant began in 1964 and was completed in 1967.

Purpose

The principal features of the Hyatt-Thermalito pumped-storage power complex are Oroville Dam, Lake Oroville, Edward Hyatt Powerplant, Thermalito Diversion Dam, Thermalito Power Canal, Thermalito Powerplant, Thermalito Forebay, and Thermalito Afterbay (Figure 59). Edward Hyatt Powerplant is the key unit of the power complex which, together with its related features, maximizes the production of power through the use of pumped storage. Under this type of operation, water released for power in excess of local and downstream requirements is returned to storage in Lake Oroville during off-peak periods and is used for generation during peak power demands.

Description

The powerplant facilities consist of an intake structure, two tunnel penstocks, six penstock branch lines, an underground powerhouse (Figure 60), three turbine units, three reversible pump-turbine units, two tailrace tunnels and outlet works, a control building, and a switchyard (Figure 61).

The plant rated generating capacity is 678.75 megawatts, and the total power for pumping is 519,000 horsepower.

The main units, turbine shutoff valves, main transformers, power switchgear, auxiliary and service equipment, emergency station service power supply, emergency control center for Edward Hyatt and Thermalito Powerplants, air-conditioning and ventilating equipment, and two overhead cranes are located in the underground structure. The underground powerhouse is operated from the Oroville Area Control Center located aboveground, adjacent to the switchyard.

Water from Lake Oroville is conveyed to the units through penstocks and branch lines. At the downstream end of the penstock branches, 114-inch-diameter spherical valves provide shutoff to the turbines and pump-turbines. After passing through the units, the water is discharged through the draft tubes to one free surface and one full-flow tailrace tunnel. The outlet portals of the tailrace tunnels are at the upstream extremity of the pool created by Thermalito Diversion Dam.

Representative drawings are included at the end of this chapter.

Architectural Design

The architectural design conforms to the State Water Project architectural motif, which was established in January 1964 and discussed in Volume VI of this bulletin. The appearance of this powerplant maintains an atmosphere of brightness and color to minimize the sensation of being underground and is similar to that of a surface generating station (Figure 62). Generous use is made of fluorescent lighting and bright colors. Red and turquoise form a symbolic color system for water and power as used throughout all of the Department of Water Resources' structures, both surface and subsurface.

The main generating room floor surface at elevation 252 feet was finished with terrazzo made with a polyester binder. This material is not only attractive but will stand considerable wear. Wall panels below the crane rails are of precast concrete surfaced with exposed quartz aggregate.

An enameled metallic ceiling is suspended from the native rock and is merged into wall panels above the crane rails. At the downstream end of the plant, an observation platform is provided for visitors. A "time vault" hermetically sealed was constructed at the main floor level in the rock wall with the closure panel visible and suitably inscribed. Eighteen boxes of documents were sealed in the vault in 1969, including plans and specifications, contracts and legal agreements, construction reports, laws and statutes, manuals, photographs, speeches, personnel rosters, and other memorabilia covering the Hyatt-Thermalito Complex and other items of interest on the State Water Project.

Geology

Areal Geology

This plant is located in the foothills on the western slope of the Sierra Nevada Range, a giant granite-cored, tilted, fault block. A series of tightly folded, steeply dipping, metamorphic rocks overlie a granite core along its western and northwestern flanks. The dominant rock type in the Oroville area is a metavolcanic amphibolite. Surficial weathering is extensive in the metavolcanic rock and is controlled by rock structures such as joints and shear zones.

Site Geology

The powerhouse is in the metavolcanic rock formation. The rock type is predominantly amphibolite, which ranges from fine to coarse-grained and from massive to schistose. Fresh rock is very hard and dense, greenish gray to black, and generally strongly

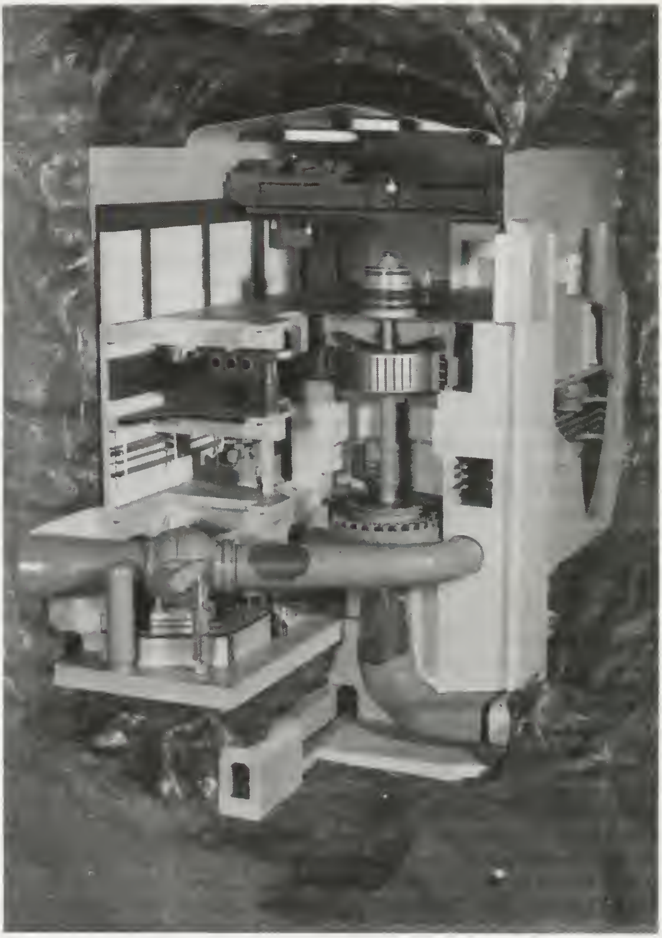


Figure 60. Edward Hyatt Powerhouse Model

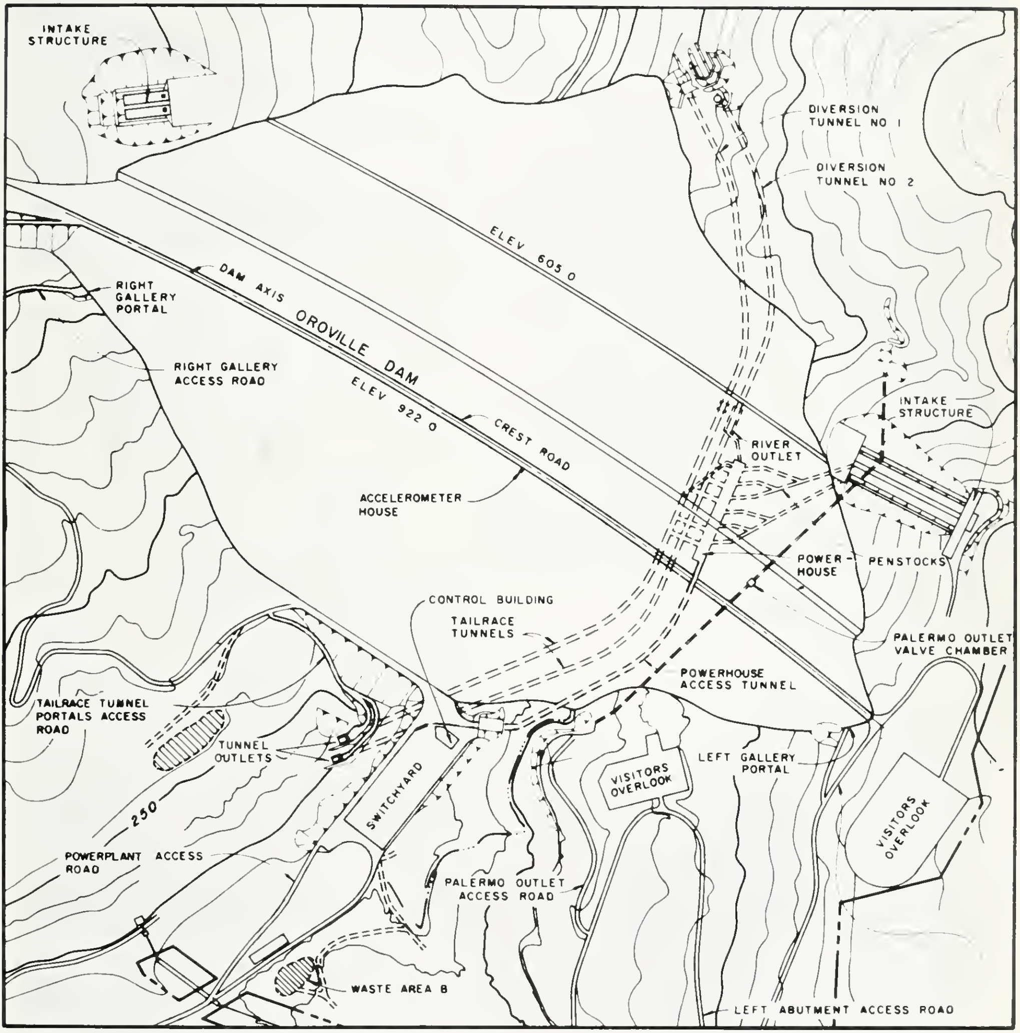


Figure 61. General Plan

Figure 62. Generator Room

jointed. Thin veins of calcite, quartz, epidote, asbestos, palygorskite, and pyrite are abundant.

In the powerhouse excavation, three prominent joint sets impart a certain blockiness to the rock, but individual joints are generally tight. Shears and schistose zones crossing the plant are generally steeply dipping, somewhat planar, and spaced from 5 to 20 feet apart. Most are from 1 to 6 inches wide and contain crushed rock and schist accompanied by thin seams and lenses of clay gouge. In general, the rock is progressively less weathered with depth. Because many of the weathered zones follow rock structures which are relatively narrow, steeply inclined, and somewhat planar, the sound rock surface at the site is quite irregular and contains many troughs and ridges. Weathering does not extend to the depth of the powerhouse excavation.

Foundation rock for the left abutment intake structure is mostly fresh and hard, but local areas of moderately weathered rock and some strongly weathered rock associated with shear zones occur in both the penstock intake and operating-storage areas. Rock in the penstock transitions is fresh and hard.

The right abutment intake structure is founded entirely on fresh hard rock. Only a few narrow shears cross the foundation surface; none was encountered in the stub penstock shafts.

Geologic Exploration

The possibility of an underground powerhouse was considered in June 1959, and the concept was first presented to the Department's Oroville Dam Consulting Board for evaluation in December 1959. Based on the results of subsurface exploration at that time, the left abutment was chosen as the most favorable location, and plans for additional exploration were formulated.

Several refraction seismic survey lines were run to determine depth of weathering and, consequently, thickness of sound rock cover above the powerplant arch. Nine Nx (approximately 3 inches in diameter) core holes were drilled to delineate the least sheared area of the left abutment.

Final exploration of the powerplant site consisted of excavating Left Exploration Tunnel No. 3 (LET-3) that intersects the southerly end of the powerhouse chamber and drilling 33 Bx (approximately 2.3 inches in diameter) core holes from the tunnel. A comprehensive tabulation of rock joint attitudes was compiled from all rock exposures throughout the dam foundation area and from LET-3 in order to determine optimum alignment for the long dimension of the powerhouse. The Department made a peg model showing major shears and joint sets.

Rock stress studies were conducted in various underground openings at the damsite, primarily in LET-3, to define the in-place stress field, deformation modulus, and relaxation properties of the powerhouse rock mass, which are described later.

Exploratory drilling for the intake structures prior to construction was limited to five holes for the right abutment intake structure; the total depths amounted to 443 feet on the right abutment and 85 feet on the left abutment. In addition, a 250-foot-deep hole was drilled for exploration of a proposed intake tower site on the left abutment. The exploratory drilling was supplemented by geophysical surveys.

Exploration within the switchyard area included bucket auger drilling and core hole drilling to investigate the feasibility of various proposed types of footings.

Instrumentation

Approximately 200 instruments were installed in the underground complex of tunnels and machine hall. These include 88 deformation meters with electrical sensors remotely interrogated and 14 such meters measured mechanically at the main operating floor, all installed to monitor deformation of the surrounding rock envelope. Additionally, the remaining instruments were installed in the structural concrete components of the Powerplant, in one of the steel-lined penstock entrances, and in the tunnel outlet plug. These include stress meters, strain meters, joint meters, pore pressure cells, and dynamometers.

The deformation of a rock envelope can be described as a convergence of the surrounding rock into the excavated opening. This convergence occurs in two stages. The first stage accompanies the excavation of the chamber and is caused by the removal of the interior rock, thus changing the stress concentration in the surrounding rock. The second stage of deformation occurs when the overburden load of the dam and water of the reservoir is added above the chamber. Recent measurements show negligible deformation due to superimposed loads of the dam and water.

Convergence of the rock arch into the opening during construction was less than predicted. Based upon in-place rock testing and stress analyses, deformation in the arch is less than 50% of what probably would have occurred in unrestrained (unbolted) rock. The 4-foot spacing of rock bolts appears to have been effective in limiting this movement. (Rock bolting is discussed later under Rock Reinforcement.) In the vertical walls, bolt spacing was 6 feet, and installation time requirements were extended to 48 hours after blasting. Average deformation in the walls was compatible with that which occurred in the unbolted rock of Diversion Tunnel No. 1, where similar measurements were made.

There has been no evidence of instability or progressive rock creep occurring in the chamber.

Seismicity

The area is considered relatively seismically inactive and generally not considered susceptible to major earthquakes. All elements of the plant were designed to withstand moderate earthquake forces (i.e., 0.1g).

Civil Features

Preliminary Studies

Preliminary studies included the following:

1. Intake structures
2. Tunnel penstocks and branch lines
3. Valve chambers
4. Powerhouse layout
5. Diversion and tailrace tunnels

These preliminary studies are briefly described in the following sections.

Intake Structures. The first proposal considered a single-level intake structure to draw water from the reservoir near elevation 600 feet. By so doing, temperatures of discharged water would range from 40 degrees Fahrenheit to 46 degrees Fahrenheit throughout the year. This would have had a detrimental effect on fish propagation, rice production, and recreation. Even with warming gained through shallower downstream flows, the water still would be too cold.

A multilevel tower was studied next. It was to be circular in plan (100 feet in diameter) and equivalent to a building approximately 30 stories high. The major element of the structure was 12 reinforced-concrete, hydraulically shaped, vertical "columns of fins" framed to reinforced-concrete rings, spaced at 20-foot vertical intervals. Control shutters lowered in slots in the fins would block inflow of water. Access schemes included either a bridge, barges, or elevated cableways, all of which contributed substantially to the initial structure costs. The tower structure was found to be structurally and economically unfeasible.

A series of similar but smaller towers critically spaced horizontally to provide continuity of service was then studied. This proposal was ruled out due to the complexity of tunneling for the penstocks and expense of providing the necessary operating equipment.

The last type of multilevel intake studied was a sloping structure which was selected for final design. A description of this intake is included under Powerplant Structures and Design Considerations.

Tunnel Penstocks and Branch Lines. Two penstock tunnels were chosen in lieu of a one-tunnel scheme to lend more flexibility in operation. Each penstock tunnel has three branch lines connecting to three units. If one of the tunnels or branches need inspection or repair, the other penstock tunnel can remain in operation.

Valve Chambers. Two schemes were studied for housing the six 114-inch, turbine, shutoff valves. The initial plan placed each valve in a separate chamber, physically isolating it from the powerhouse proper. The advantage of this arrangement is a greater degree of safety should a rupture occur in the valve or portion of penstock located in the separate chamber.

In the second scheme, adopted for final design, the valves were placed in the powerhouse chamber.The advantages of this scheme were twofold: less rock excavation, and the need for an extra crane was eliminated since the valves can be serviced with the powerhouse bridge cranes. Factors of safety for the valves and penstock transition with this arrangement were increased by using conservative design stresses and high-strength steels.

Powerhouse Layout. Preliminary design of the powerhouse included several alternatives. Surface and underground schemes were considered. While the conventional scheme represented a surface power plant located at the toe of the dam, the underground scheme studies included several possible plant configurations. A spherical rock cavern with a circular power plant and a typical rectangular rock excavation housing a simple in-line arrangement of units were investigated. Separate economic studies were made for the location of the main transformers. As a result a single, rectangular, rock cavern housing all equipment, including the transformers and penstock valves, offered the most economical design. The main problem was to provide adequate space for the turbine shutoff valves and to keep the overall width of rock excavation to a minimum, thus providing for a design in which the rock arch forms a dependable and self-supporting roof structure.

Rotation of units is counterclockwise when generating and clockwise when pumping. This was chosen because of the orientation of penstock branch lines and the economy of space.

Diversion and Tailrace Tunnels. The preliminary design studies of the two diversion tunnels took into consideration their use as tailrace tunnels for the powerhouse. This governed their vertical and horizontal alignment. When diversion of the river was no longer required, the diversion tunnels were plugged upstream of the powerhouse location, and the draft tubes were connected to the tunnels. Hydraulic model studies of the draft-tube connections to the diversion tunnels for power operations were conducted under contract by the U.S. Bureau of Reclamation in their hydraulic laboratory in Denver, Colorado. The basic designs prepared by the Department of Water Resources were finalized through these model studies. Additional description of the diversion tunnel layout and structural design is contained in Volume III of this bulletin.

Site Development and Drainage

Site development comprised mostly underground construction activities and, concurrently, aboveground site locations for various facilities were developed. Site development consisted of excavation for the intake, two penstock tunnels, six branch lines, powerhouse access tunnel, powerhouse, diversion tunnels, control building, switchyard, access roads, facilities for domestic water and sewage treatment, and disposition of spoil. Site drainage included temporary drainage during construction and permanent site drainage for the control building and switchyard areas. Site development for all other facilities was provided in conjunction with Oroville Dam.

Access to the Powerplant is by a road included in the system providing access to all Oroville Dam facilities. The road net leading to the powerhouse access tunnel is the only route available for transporting heavy equipment to the underground powerhouse.

The location of the intake structure on the ridge upstream of the left abutment of the Dam was governed by the underground powerhouse location. A large double-channel excavation was required for the sloping portion of the intake, and structural excavation was required for the operations and maintenance area. Material removed from this area was spoiled in designated waste areas. Drainage during construction and storm runoff from the site were allowed to drain to the river below.

Excavation of the diversion tunnels preceded that of the powerhouse. Work on Diversion Tunnel No. 1 was complicated because the upstream portal was directly beneath the Western Pacific Railroad, and access to the site was across a temporary bridge crossing the Feather River from U.S. Highway 40A (now State Highway 70). Excavation for Diversion Tunnel No. 2 was less complicated since the Railroad and Highway had been relocated, eliminating the need for maintaining railroad and highway traffic flow. Material removed from the tunnels was spoiled in designated waste areas, and some rock was used in cofferdams, roads, and switchyard embankment. Ground water seeping into the tunnel was pumped to the surface for disposal into the River.

The switchyard was placed as close as possible to the entrance of the powerplant access tunnel. This necessitated constructing a large fill on the left bank of the River with materials removed from the powerhouse and penstock excavations. This became the location for the switchyard and control building.

The drainage system for the switchyard consists of intercepting ditches on the hillside above the yard and a system of underdrains and ditches to handle water in the immediate yard area.

The ditches are lined with pneumatically applied mortar. Backfill around the control building is drained by a perforated underdrain which discharges into the underground system for the switchyard. The collected runoff is discharged into the River.

Raw sewage from the Powerplant is pneumatically ejected to a septic tank located near the control building. Sewage from the control building also flows to this septic tank. After undergoing treatment, effluent from the septic tank drains to a lift station and is pumped to stabilization ponds located downstream of the switchyard for further treatment. Effluent from the ponds is then disposed of in a leach field system farther downstream.

Powerplant Structures and Design Considerations

Intake Layout and Design. Water must be released from the reservoir at temperatures suitable for fish life and agricultural purposes. Therefore, a sloping intake structure capable of withdrawing water from various reservoir levels, and consisting of two rectangular channels equipped with water-level control shutters, was selected. The flow area of each channel is approximately 1,100 square feet, and the inflow level is controlled by shutters. The intakes extend from the penstock inlet at elevation 613 feet to the intake operating deck at elevation 922 feet. The operating deck contains the control building and equipment needed for operation and maintenance purposes.

The main intake gates are designed for normal and emergency closure; thus the penstocks can be dewatered at any time (Figures 63 and 64).

Operating Deck Structure. The operating deck structure houses electrical and mechanical equipment and has storage bays for storing and maintaining control shutters.

The foundations for the structure were designed for adequate stability and maximum security against erosion. Spread and stepped footings were used. Eighteen-inch walls extend from the foundation to the floor level. Free-draining gravel blankets on both sides of the foundation walls equalize hydrostatic loads. Weep holes also are provided.

Eight-inch, asphalt-coated, perforated, corrugated-metal pipe was provided along the back wall of the deck structure to intercept ground water.

Intake Channel. The rectangular intake channels extend from the penstock inlet up to the operating deck structure, a length of 650 feet (Figure 65). The channels are founded on rock on a slope of 1.9:1. The invert slab is firmly anchored to the rock, and the vertical side walls are cantilevered 35 feet from the invert slab. Near the junction with the penstock, the rectangular channel side walls converge to the same width as the penstock inlet in order to minimize head loss and simplify the intake gate design. Gate slots in the concrete are lined with stainless-steel plates.

Figure 63. Overall View of Intake

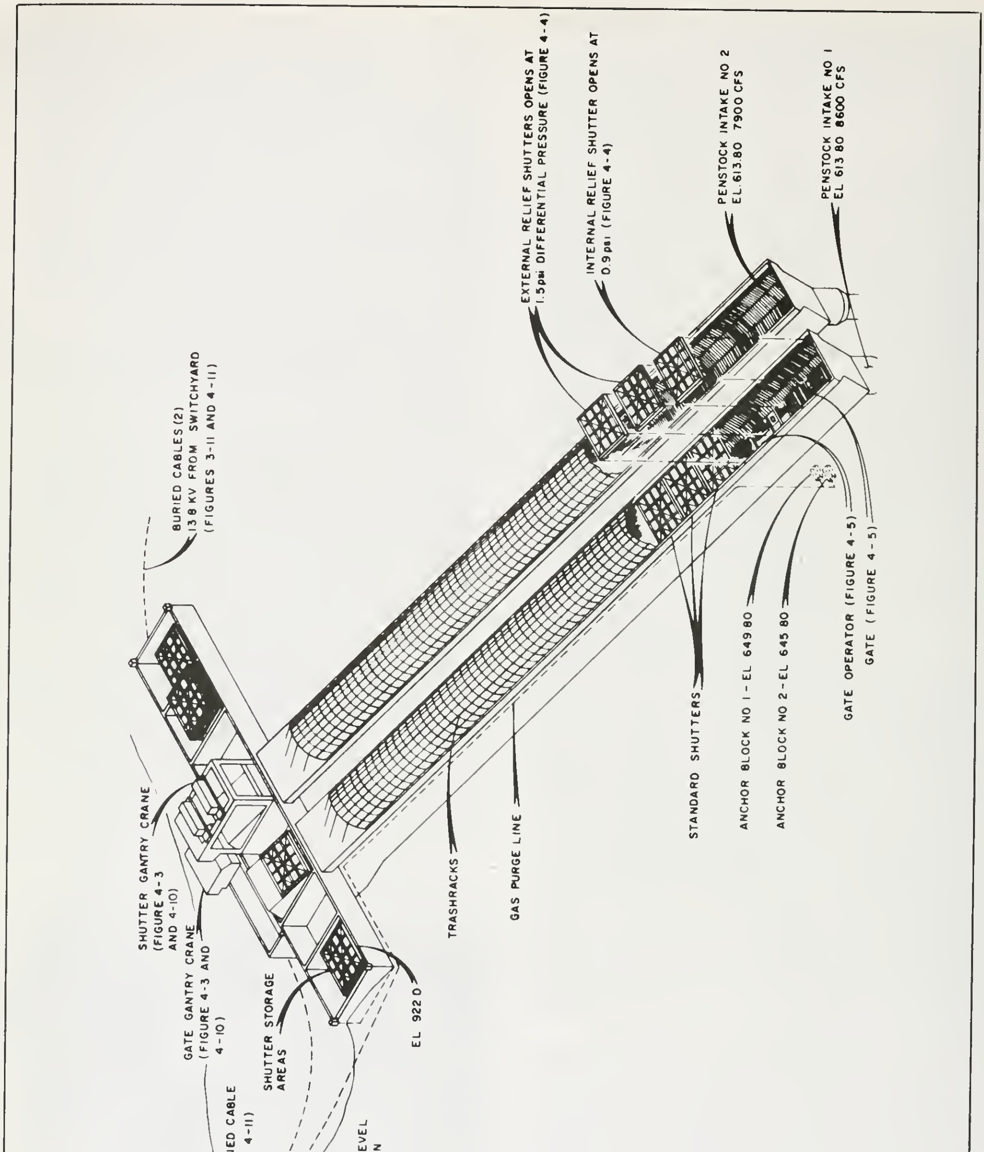


Figure 64. Intake Structure

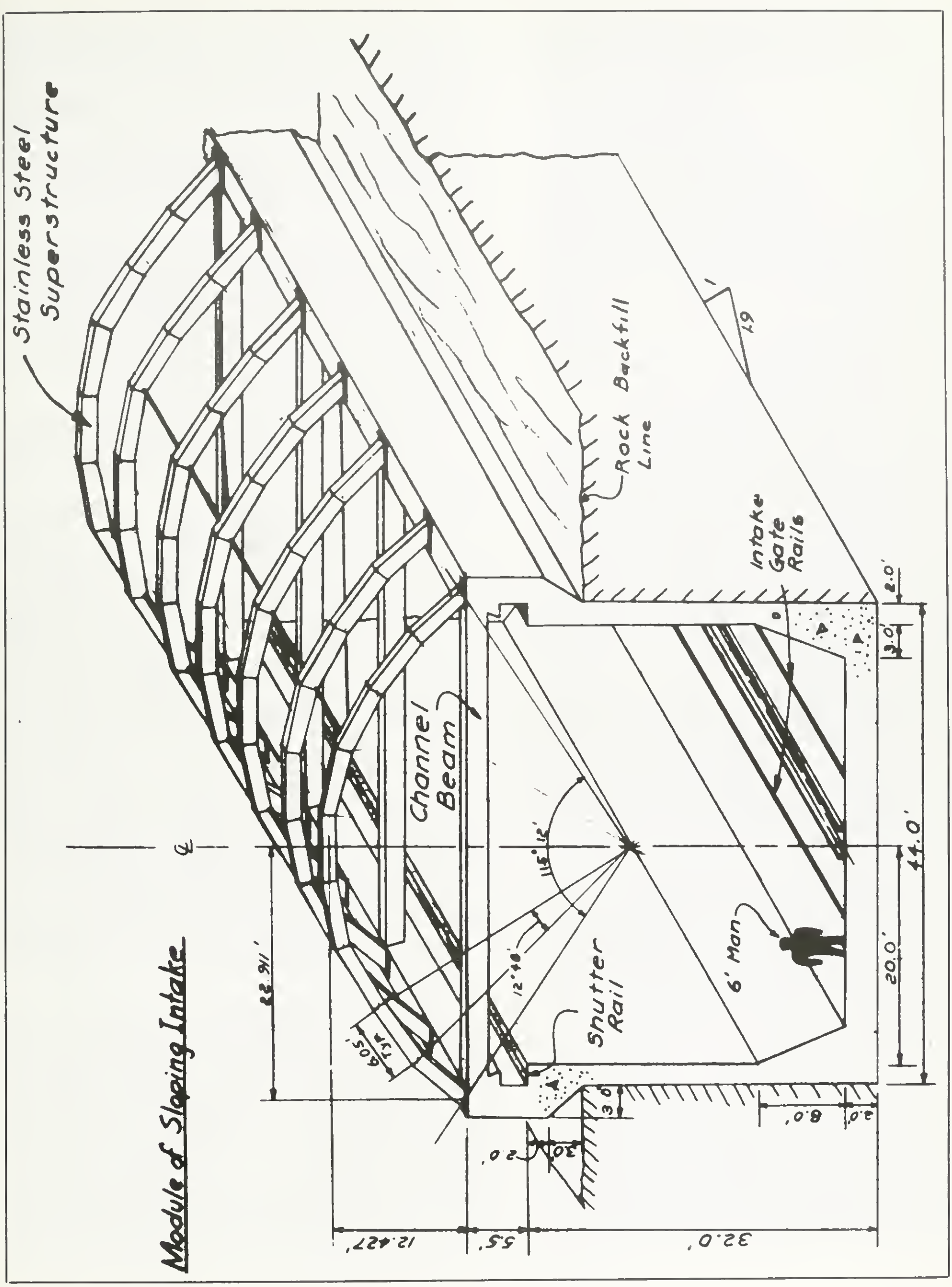


Figure 65. Channel Section

The intake channels are anchored to the foundation by a combination of shear keys and stressed rock bolts. Stressed rock bolts were designed to tie the channel and the jointed foundation rock into a structural entity.

The high channel walls, with free water on both sides, exposed a large area for hydrodynamic seismic loads. For large deflections in the freestanding channel walls, the original design called for tying the two walls together with channel beams. The control shutters were to be 40 feet long, and channel beam spacings had to be such that their sum equaled 40 feet. Secondly, the channel beams were to be designed to limit deflections to within tolerable limits. Channel beams located at 13-foot - 4-inch intervals were to be of composite construction and accommodate large reversible moments and thrusts. The design consisted of a wide-flanged member wrapped with welded wire fabric and encased in reinforced concrete.

Because of the poor foundation encountered during excavation, the trashrack support structure for the penstock intakes had to be completely redesigned. The original concrete arch-strut system required full fixity at its abutments for structural integrity. The strutted, box-shaped, channel structure could not fulfill this design requirement. The need for a trashrack support structure having greater flexibility than the reinforced-concrete design was obvious. Designs were compared for a system of circular arches, gable trusses, and horizontal beams. Of the three, the arch system proved most economical.

Spacings of trashrack support arches were related to the channel beams. They were designed to function as a tie for the arch supports. But, with the arches spaced at 13 feet - 4 inches, the beams between the arches were required as well as cross beams to support the trashrack panels. Therefore, a framing system having arches at 6-foot - 8-inch centers was adopted which eliminated all beams, thus reducing and simplifying connections.

Penstock Transition. That part of the structure from the rectangular penstock inlet at the channel invert down to the 22-foot-diameter penstock is designated the penstock transition. The penstock changes smoothly from a rectangular shape to a 22-foot-diameter circular section. Convergence and divergence of sides were held to less than 5 degrees and abrupt changes were avoided.

Loading of the transition section was presumed at 125% of the hydrostatic head acting either internally or externally. The rectangular section was designed as a box frame resisting applied moment at the corners. The circular section was designed as a ring.

Intake Trashracks. Intakes for onstream hydroelectric plants require an effective means to prevent damage to turbine parts caused by debris in the water. The intake trashracks provide this protection.

The overall size of the trashrack system and its support structure, coupled with its long-term corrosive environment, make the definition of design loads, the selection of the structural scheme, and the selection of design materials important. Design loads for the trashrack support structure included the structure dead load, hydrostatic live load, hydrodynamic seismic loads, wind and wave loads, support movements, and temperature loads. Because of the steep channel slope, the out-of-plane dead load component became significant.

A careful study selecting the proper material for the trashracks and trashrack supports was warranted. A study was conducted on continually submerged materials. Materials considered included carbon steel, low alloy steel, wrought iron, aluminum, and stainless steel. Major advantages of stainless steel are its corrosion resistance, not only on its surface but throughout its entire section, and that it can be cold worked to high strength and is a weldable material.

The development of a design using high-strength, stainless-steel, hollow tubes for trash bars and light-gauge sheets and strips for the support members made a very lightweight structure.

Load criteria for the trashracks included live load, impact load, hydrodynamic seismic load, and dead load. The hydrodynamic seismic loading was evaluated using the "Cylinder Analogy" which was found in all cases to be less than other design load conditions. Trash-bar thickness was made sufficient to allow the trash bars to span between the arches (6-foot - 8-inch centers) without additional, intermediate, lateral supports. When the design was completed, the most efficient shape was found to be a hollow, rounded, rectangular tube fabricated from ¼-inch, hard, stainless-steel tubing.

The trashrack support angles secure the trash bars into a system of panels. This angle is a designed, Type 304, stainless-steel extrusion. This technique was selected because it allowed a cross section to be prepared which fit all requirements for the support member. These panels were totally shop-assembled into uniform interchangeable units. All bolt holes were prepunched into a uniform pattern. To cover the total trashrack area, 810 panels were required. Eighteen specially shaped trashrack panels were required for the end closures.

During the acceptance testing period of the powerplant systems, the Department was alerted to vibration problems that had just occurred at another pumping-generating installation during the pumping mode. It was learned that the vibrations were caused by the so-called Von Karman effect that excited certain structural members during the pumping mode. This is the turbulence created in the wake of flows traveling around a bar. Tiny vortices are rapidly formed and then shed, first on one side of the bar and then on the other, regularly alternating back and forth. Given proper conditions, Von Karman effects can readily set the bar into motion and, if in resonance with the structural element, may cause rapid failure by fatigue.

To circumvent vibrations during the pumping cycle, all the trashracks and shutters in the vicinity of the pump flow jet directly above the penstock openings were removed.

The up-channel flow intake was reduced by placing internal relief shutters in lieu of regular shutters directly in line with the penstock opening. A description of these shutters follows later under Internal Relief Shutters. No measurements of the flow escaping through the relief openings were made, but air model studies made by the University of California at Davis indicated this to be about 33% of the total volume pumped. Hydraulic studies further verified this result. The remaining channel flows contained no pockets of high velocities and were no longer critical to trashrack vibrations. A minimum of three shutters was required to turn the jet completely up the channel. Velocities through the relief openings were high, and this would have had detrimental effects on the trashracks had they not been removed. The model testing indicated that the jet could be deflected with shutters and even more favorably with the internal relief shutters in place at the bottom.

The flow escaping through the relief shutters appeared on the reservoir surface as a compact boil about 50 to 60 feet across. No measurements could be made of the velocity of the flow escaping through the shutters.

After approximately three years of operation, evidence of failures of some trashrack bars was noted during a routine maintenance inspection. After conducting a testing program, it was learned that trashrack bars were resonating due to the effects of Von Karman vortices occurring during generating flow. Up to this point in time, little pumping had been done. To alleviate the problem, lateral stabilizers made of butyl rubber were placed between the bars and braced with diagonal bracing. Test results showed that the magnitude of the forces created by vibrations was reduced from 2.15g to 0.1g for spans having diagonally stayed lateral stabilizers. These reduced forces and the large increase of damping provided by the lateral stabilizers will assure satisfactory operation of the system.

Temperature Control Shutters. The temperature-controlling capability is provided by flat, rectangular, fixed-wheel gates or temperature control shutters. These are lowered from the storage bays by the shutter gantry into the channel on rails embedded near the top of the channel walls. The first shutter bears on the end block; each successive shutter bears on the preceding one. Thus, this line of shutters prohibits water from entering the intake channel below the uppermost shutter. By lowering additional shutters or withdrawing them from the channel, water may be drawn from varying levels in the reservoir, depending on the desired temperature of releases made.

Emergency and normal regulation of the power generating units can cause severe shutter loading conditions in the intake structure. Without pressure relief, transient studies of head rise near the penstock inlet indicated an upsurge of 25 feet during load rejection and a downsurge of 20 feet during load acceptance. To maintain differential pressure within acceptable limits, the lower-most control shutter in each intake contains an intake internal pressure relief system. The next two control shutters in each intake contain an external pressure relief system. The remaining ten in each intake are standard shutters having no relief openings and are closed off by metal decking.

The basic structural framework for all the control shutters is the same. It consists of two wheel housings; five girders (two end and three intermediate) spanning between channel walls; curved plates attached to one end for a seal and the other for hydraulic efficiency; and all necessary stiffeners, lateral bracing, and tension rods for stability during handling and transportation. Each shutter is prefabricated in four units, with the field joints at the centerline of the intermediate girders.

Internal Relief Shutters. Internal overpressures caused by pumping or load rejection by motor-generators are easily reduced to tolerable limits. A 25-foot upsurge in pressure would be created by simultaneously rejecting all power generation. However, by diverting excess flows through relief vents, the surge is limited to that required to eject this excess. The internal relief system for each intake consists of 64 flap panels mounted eccentrically on axles and fitted within the framework of one control shutter.The panel weight is used to hold them closed until it is exceeded by the force from internal overpressures. Each panel is 3 feet long by 4 feet - 4 inches wide. Its axles are mounted in water-lubricated, fluorocarbon, resin bearings. When pressures are relieved, dead weight restores the panel to its normal closed position. With 64 panels, 832 square feet of relief area is provided.

External Relief Shutters. External overpressures exist whenever power demand increases. A maximum 20-foot downsurge would be created in Intake No. 1 when the two turbines and one pump-turbine pick up load at the maximum rate of 100 megawatts per minute. The system had to provide relief when needed and return to its normally closed position at other times.

The system adopted consisted of torsion springs installed and preloaded so the panels would remain closed until an external overpressure in excess of 3.5 feet of water occurred. Additional differential pressure will force the panels open. Through model tests conducted by the U.S. Bureau of Reclamation, the response of each relief panel was determined. This determination included opening torque and discharge related to gate opening. Having this information, it was determined that 64 external relief panels would be required for each intake channel. Because of the size of each relief panel, including the attached spring system, two shutters were required to contain the number of panels required.

Additional capability for external relief is provided by the internal relief panels. The lip of each internal relief panel is hinged and held in place by bolts designed to fail in tension should external overpressures exceed 7.5 feet of head. This loading approaches 80% of the ultimate strength of the control shutters. This back-up system was designed to actuate if, for some unforeseen reason, the external pressure relief system failed to limit the head rise to 5 feet as designed.

Power Tunnels

Penstock Tunnels and Branches. Two circular, concrete-lined, penstock tunnels, each dividing into three branches, serve the six generating units in the plant. The branches vary from 800 to 900 feet in total length. A transition section connects the circular penstock with the intake base. The 22-foot-diameter penstocks begin as vertical shafts at the lower end of the inclined intake structure, bend to 55-degree inclined shafts, level out at approximately elevation 215 feet, and then branch out to each unit and enter the powerhouse at elevation 205 feet.

The tunnel layout was based on economics as well as the general relationship between the Dam and plant. The shortest tunnel best suited for anticipated construction methods was chosen. Control points determining the basic layout are as follows: (1) the intake structure was located for convenient access with respect to the embankment and powerhouse, (2) the angle of branches entering the powerhouse was controlled by plant layout, and (3) a straight penstock ten times the diameter in length was provided immediately upstream of the units to assure uniform velocity distribution at their entrance.

Penstock No. 1 serves two turbines and one pump-turbine, and Penstock No. 2 serves one turbine and two pump-turbines. Maximum velocity in the penstocks is approximately 25 feet per second. A 45-degree angle is used between the main penstock and branches to improve the hydraulic efficiency of the bifurcations. A steel liner is used in the last 100 feet of the branches to: (1) provide a high-quality surface immediately upstream of the scroll cases, (2) prevent high water pressures in the penstock from leaking into the rock immediately surrounding the powerhouse, and (3) provide for convenient installation of instrumentation for flow measurement.

Concrete Tunnel Lining. Concrete lining was used in the tunnels to ensure a smooth interior surface to limit head loss, prevent rock fallout, and minimize seepage into the surrounding rock. The limiting cases for tunnel lining loading are: (1) full reservoir pressure on the outside and zero inside, and (2) full reservoir pressure on the inside and zero hydrostatic outside. Design of the concrete lining for internal pressure was based on distributing the load between steel reinforcement and the surrounding rock. Analysis indicated that the stress in the hoop reinforcement would be approximately 10,000 pounds per square inch (psi) with the measured rock modulus. Reinforcement steel, in the amount of 0.3% of the concrete area, was used to ensure that any cracking caused by a net pressure on the inside is fine and well distributed. The steel liner was designed to resist the full reservoir on the inside and on the outside with the penstock empty.

Grouting. The grouting program for the penstocks included consolidation grouting of the rock surrounding the tunnels, contact grouting the voids between the concrete lining and rock, and contact grouting the voids between steel liners and concrete backfill. Filling all voids by contact grouting and increasing the competency of the surrounding rock by consolidation grouting are of utmost importance to minimize cracking of the tunnel lining should an unbalance of hydrostatic pressures result in pressure on the inside.

Draft Tubes and Draft-Tube Tunnels. The draft tubes from Units Nos. 1 and 2 connect to Diversion and Tailrace Tunnel No. 2, while those from Units Nos. 3 through 6 pass under Tunnel No. 2 and connect to Tunnel No. 1. Surge ports from draft tubes Nos. 3 through 6 connect with Tunnel No. 2. The draft tubes and tunnels are lined with reinforced concrete.

The exhaust way from the units is divided into two main reaches: the draft tube, and the draft-tube tunnel. The draft tube connects to the base of the scroll case with a circular cross section; forms an elbow which transitions into a broad flat rectangle; and then, split by a center pier, transitions into a circle. Hydraulic model studies conducted by the turbine manufacturer (Allis-Chalmers) verified the efficiency of draft tubes transitioning to circular sections. As the draft tubes are underground and subjected to high external hydrostatic pressures, it was desirable to use partial circular sections to take advantage of the arching of the concrete lining and the surrounding rock excavations.

Since velocities are quite low (a maximum of approximately 25 feet per second), a concrete surface finish was specified allowing abrupt irregularities up to ¼ inch and gradual irregularities up to ½ inch.

Elbow portions of the draft tube and a short reach of the horizontal section are steel-lined. The reach of circular tunnels connecting the transitions to the diversion tunnels are designated as the draft-tube tunnels. The tunnels from Units Nos. 1, 3, and 5 are 21 feet in diameter, and those from Units Nos. 2, 4, and 6 are 18 feet in diameter.

That portion of the draft tube extending outside of the powerhouse structure is subjected to external hydrostatic pressure less than that of full reservoir as it is downstream of the dam grout curtain and in the zone of influence of the powerplant drainage system. Drain holes were drilled through the lining into the rock at the invert of the tunnels to further ensure a reduction in external pressure. A design external pressure of 50% of the reservoir head was based on the electrical analogy studies conducted for the powerplant complex.

Sections through the draft-tube transitions were designed as elastic arches subjected to the external load plus dead load. The internal dimensions of the sections are symmetrical about both the horizontal and vertical axes, and reinforcement is placed as such. Fixity is assumed at the point the arch joins the center pier. Investigations showed that the loading on the pier produced negligible deformations; thus, rib shortening or abutment movement were not factors in the design of the arch.

The circular draft-tube tunnels were designed as thick wall cylinders subjected to the loading as previously mentioned. Where reinforcement was not required for structural reasons, it was placed longitudinally and transversely in the tunnels to preclude excessive cracking of the concrete.

Powerhouse Layout and Design

Powerhouse Chamber. The total length of the powerhouse chamber including the erection bay is 550 feet, its width is 69 feet, and its excavated depth is 137 feet.

The draft-tube tunnels are approximately elliptical in shape at the junction with the powerhouse chamber. The horizontal and vertical axes of the ellipse are 36 and 20 feet, respectively. The 15-foot-diameter excavated penstock branches enter the powerhouse chamber at elevation 205 feet.

The roof of the powerhouse excavation forms two circular arcs with a rise of 19 feet and maximum width of 72 feet at the section through draft-tube gate slots. As previously stated, the problem was to house exceptionally large equipment with economy and safety of excavation. For this reason, the roof span of the main cavern was kept to a minimum, and rock stabilization was achieved by rock bolting and grouting.

Analysis of Rock Stresses. In preparation for design of the powerhouse chamber, it was necessary to determine rather closely the magnitude of the stresses already existing in the rock mass. The methods and devices used have been used on other occasions; however, the extent and the particular combination of these methods utilized in this investigatory work are deemed worthy of mention. In general, the methods of investigation used in the exploratory adits of the machine hall chamber were: (1) diametral jacking, (2) flatjack testing, and (3) bore hole stress relief testing.

The diametral jacking technique measures the in-situ deformation modulus of the rock mass, a parameter differing from the elastic modulus in that it includes the effect of joints and discontinuities as well as the intact rock. The modulus must be known to properly design openings in rock and to design structures acting in conjunction with the rock. As the name implies, the process consists of applying a jacking load between the diametrically opposite walls of an adit or gallery excavated in the rock and measuring the deformation produced in the rock by these loads. By using the measured load and deformation in equations derived from elastic theory, determination of the modulus of deformation is made.

In the flatjack method, precise measuring points are first established in the rock and then a slot is cut passing between the points. The change in distance between the points, due to the removal of the restraint of the rock between them and the force which it is necessary to apply by means of a flatjack inserted in the rock to restore the measurement between the points to its original value, provides an indication of the stress formerly existing in the rock and the modulus of elasticity of the rock. By orienting the planes of these slots in the walls and ceilings of tunnels or adits, it is possible to determine the stresses in three mutually perpendicular directions.

The bore hole method of stress determination was a development by the U.S. Bureau of Mines and, in this instance, was applied to the work on this facility jointly by the Department and the U.S. Bureau of Mines. This method consists of drilling an NX hole into the rock and inserting a sensitive gauge which, through electrical means, senses and indicates on external instruments the diameter of the hole and changes in the diameter of the hole with great precision. After this gauge is installed in the 3-inch hole, a 6-inch drill is brought into play and "overcores" or cuts an annular groove concentrically around the original 3-inch hole to a sufficient depth to relieve any stress which was originally acting on the rock at the gauge location. With the restraint of the outer rock removed by the overcoring, the bore hole gauge in the 3-inch hole will measure rock expansion due to the removal of the external loading.

The modulus of elasticity of the concentrically drilled core also is required. It is determined directly by taking a section of the core and placing it into a testing machine in the laboratory and measuring the deformation under a known externally applied load. Additional computations are then performed to determine the original stress in the rock mass.

All three methods produced reasonably consistent results and indicated a stress condition in the rock mass very nearly hydrostatic i.e., equal stresses in all three directions at about 500 pounds per square inch. The modulus of deformation of the rock mass was established for design purposes at 1.5 million psi, with indications that somewhat higher values might be expected in areas with lesser intensities of jointing.

The above parameters were utilized first in design studies of stress concentrations around the periphery of the underground chamber and, secondly, in predictions of arch and wall deformations to be expected during excavation of the opening. Analyses in two dimensions were made, utilizing both the conventional elastic models of an elastic plate with an elliptical hole approximating the machine hall opening, and also of a finite element mesh which more precisely approximated the irregularities of the opening. In both cases, homogeneous elastic properties were employed based upon the results of the above-described tests.

The finite element method of stress analysis was proposed by its originator, Dr. R. Clough of the University of California, at about the same time that design work was being undertaken on this plant and was employed extensively therein. An opening in the anticipated cross section of the powerhouse chamber was assumed to be cut in the rock mass which, as a whole, was subject to the measured stress field of 500 psi in all directions. The interior boundary of the opening was unloaded at the sides, top, and bottom, while the known loads were applied to suitably distant boundaries of the rock mass representation.

Rock Reinforcement. Rock reinforcement consisted of rock bolts, chain-link fabric, and guniting of the entire roof and a portion of the walls. Since the underground chamber represents a large areal extent of excavation, a general pattern of bolting was chosen for rock reinforcement. In addition, specifications were developed to state that rock reinforcing shown on drawings was typical only, and modifications directed by the engineer would include variations in the pattern, spacing, and length as conditions might require. This decision was made on the basis of geologic and tectonic conditions as well as direct observation of rock.

Two basic patterns of bolting were designed to strengthen and to stabilize the rock: (1) the powerhouse roof was bolted with 20-foot-long, 1-inch-diameter, high-strength bolts spaced approximately 4 feet on centers; and (2) all vertical rock faces, except those adjacent to benches in the lower levels of the machine hall, received the same size bolts, except that the spacing was increased to approximately 6 feet on centers. Additional bolts were used at the junction of various tunnels with the powerhouse chamber and in areas where special treatment of rock was required.

Immediately after blasting, the bolts were installed as close to the working face as possible. Early installation of rock bolts is essential to enhance the safety of rock excavation and to minimize further relaxation of the so-called decompression zone at the excavated surface. Bolts were anchored in place by an expansion anchor, tensioned to a specified stress, packed and sealed at the rock face, and finally grouted.

Grouting. Results of a series of tests on effects of grouting in completed projects indicated clearly the importance of grouting and consolidating the rock. Ungrouted fissured rock may be subject to yield and deformations that may be undesirable. In general, tests have conclusively proven that grouting not only closes the fissures but also considerably increases the value of the modulus of elasticity and the structural integrity of the rock. This is synonymous with a decrease of its deformability and, consequently, a substantial decrease in the possibility of raveling.

A second important function of rock grouting is the reduction and control of seepage from the reservoir above the Powerplant. The rock structure with tightly grouted joints reduces the inflow of water to quantities that are readily controlled by the drainage system.

Envelope grouting from the powerhouse excavation chamber overlaps the grouting from the tailrace tunnels. The end walls of the chamber are protected in a similar manner.

Figure 66 shows a typical cross section of the rock area around the periphery of excavation divided into three zones. The ungrouted zone extends a distance of 40 feet from the excavated face. This zone was not grouted in order to avoid a buildup of pressures due to the grouting itself and the pressure buildup that would occur near the rock surface due to seeping water.

First-stage grouting began at a depth of 40 feet and extended to a depth of 60 feet with pressures up to 100 psi, thus providing a transition to the high-pressure grout zone. The high-pressure zone was grouted with pressures up to 300 psi in a depth interval of 30 feet. It constitutes the main barrier against the seeping water. Thus, the water pressure will be exerted at a considerable distance from the actual face of the excavation where increased rock stresses will be safely distributed by the rock structure.

Drainage and Seepage—Analog Model Studies. Electrical analog model studies were conducted to evaluate the probable drainage pattern permitted by the rock mass permeability. The studies demonstrated that a simple grout curtain would be of little help in

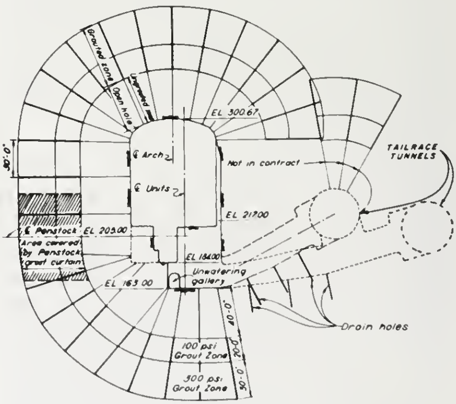


Figure 66. Zone Grouting

attenuating a buildup of pressures near the boundary of the opening, but a combination of grouting and drainage of the rock conducted completely around the arch and walls of the powerhouse chamber would produce satisfactory results.

Data obtained from the model studies did not necessarily permit an accurate plotting of the pressure envelope. However, on the basis of the results obtained from the studies, it was possible to establish valid and adequate design criteria.

Drain holes were drilled in the rock surrounding the powerhouse, draft tubes, diversion tunnels, and access tunnel after envelope consolidation and contact grouting were completed. Provisions were made for additional future drains where required. The minimum diameter of holes was specified to be not less than that produced by a standard NX size drill bit. The spacing of drain holes is approximately 25 feet; their length varies from 25 to 48 feet.

The water from the roof is intercepted by the suspended ceiling and drains by gravity into the peripheral gap between the structure and the rock. The seepage from the drain holes around the Powerplant is collected by the pipe drainage system installed below elevation 217 feet and flows into a drainage sump in the service bay area. The drainage water is pumped into the tailrace with automatically controlled pumps.

Structural Behavior Instrumentation. Rock deformation meters, joint meters, concrete stress meters, and concrete strain meters were installed to observe and record the structural behavior of rock and concrete (Figure 67). In addition, pore pressure cells evaluate residual hydrostatic pressure between the powerhouse substructure and rock.

Of prime interest is the deformability of the rock mass immediately after blasting, rock behavior due to the load resulting from inundation of the reservoir and, finally, changes in rock stresses during the useful operating life of the Powerplant.

Presence of joints in rock constitutes the most significant difference between rock in situ and a laboratory specimen. Jointed rock is neither homogeneous nor isotropic; therefore, deformation measurements in situ are considered to be most significant in ascertaining the behavior and structural integrity of rock.

The deformation of the rock arch was continuously monitored during its excavation. For continuity, two different types of deformation meters were employed in two stages.

In the first stage of monitoring, approximately 40 specially designed rock-bolt deformation meters were installed. The meters were 20 feet long, relatively immune to blast damage, and monitored manually with a laboratory-type dial gauge reading to the nearest 0.001 inch. The specific locations for these meters were selected in the field by the project geologist. Greatest concentration of meters occurred in those areas of the arch which first emerged and were accessible during construction. These manually observed meters were abandoned during the benching phase of machine hall excavation when they became unreachable.

The second phase of monitoring deformation required the use of remotely interrogated deformation meters with electrical sensors. These, too, were specially designed with the objective of providing permanent, or at least long-period, monitoring of the chamber. They were 40 feet long and thus capable of registering deformation in the 40-foot-thick envelope of rock adjacent to the chamber. The sensors were responsive to the nearest 0.0001 inch of movement.

The instruments were placed in various orientations at the centerline of each generating unit and in two additional sections in the erection bay area. Fifty-two devices were installed in the arch of the chamber, and 32 more were installed later in the walls when access was available at the approximate mid-elevation of the chamber cross section.

Immediately prior to the benching phase of excavation, and with the entire arch opened up and reinforced, further stress measurements were made along the centerline of the long axis of the chamber. These tests employed the bore hole stress relief procedures described earlier. They were performed in nine vertical holes ranging from 8 to 11 feet deep.

These were dual-purpose tests, intended first to confirm the existence of the predicted design compressive stress components in the tangential direction across the arch and, secondly, to make a determination of the magnitude of the stress component existing parallel to the long axis of the chamber, a component not evaluated by the two-dimensional design studies. The tests verified that the longitudinal component of arch stress in every case was compressive to a satisfactory degree.

Construction Crane. Construction crane runways were mounted on steel girders supported by steel columns. Columns and girders were erected immediately after the excavation was completed in order to make them available for the support and operation of two 25-ton-capacity construction cranes. The lower part of the W16X45 (16WF45) column was designed to carry the construction crane load only, and the upper portion, W21X96, was designed to support the load of the two permanent cranes, each 200-ton capacity. Both sections were eventually embedded in concrete, and that portion of the column which projected above the main floor at elevation 252 feet was designed as a composite section.

During the construction period, columns were braced to the rock to obtain a desired slenderness ratio. Bracing was removed after concrete had been placed around the columns. The crane girders are supported laterally with assemblies consisting of 1-inch-diameter, stainless-steel, grouted, anchor rods and 3-inch-diameter, extra-strong, galvanized pipe spaced at 5 feet on centers.

Structural Design and General Layout. The pow-

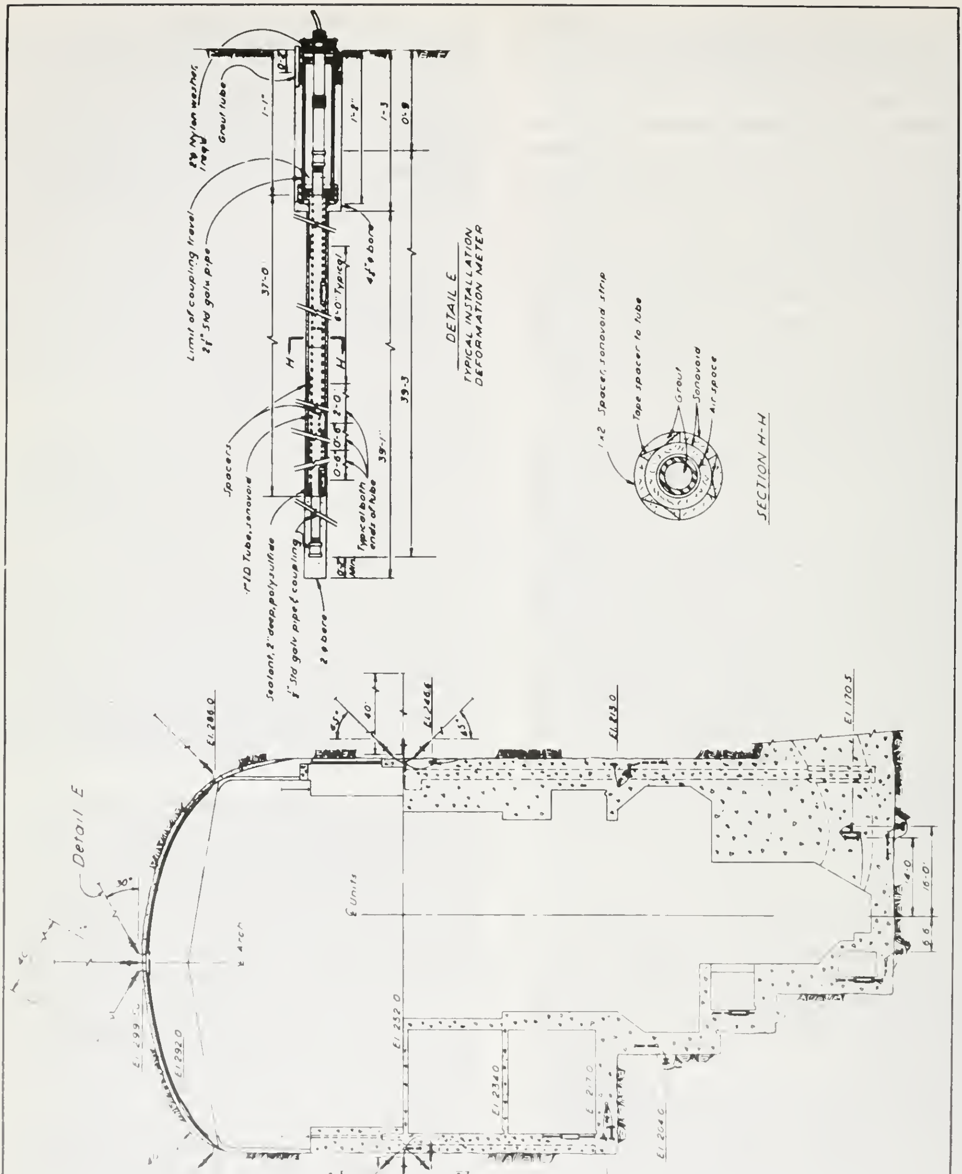


Figure 67. Rock Instrumentation

erhouse substructure is placed directly against the rock. The problem of stability was eliminated because the substructure is well keyed into the rock, and the uplift and hydrostatic pressures are alleviated by the drainage system. A portion of the substructure, beginning at elevation 217 feet, is separated from the rock in order to eliminate undesired effects of possible rock squeeze and to facilitate free drainage.

Design loads for various floors were evaluated on the basis of the size, placement, and handling of major equipment (Figure 68). The amount of reinforcing steel was determined from structural computations as well as from the requirements for shrinkage and volumetric changes of concrete. Control of shrinkage cracking was provided by the carefully planned system of the construction joints and the limitation of concrete placement temperature to as near 50 degrees Fahrenheit as could be obtained by specified means.

Most of the powerhouse structure designated first-stage concrete and delayed first-stage concrete was completed under the initial contract. A relatively small portion of concrete designated second-stage concrete, which was required for encasement of scroll case and supporting of the generators and motor-generators, was placed under a completion contract.

The generators and motor-generators are set in a straight line, and optimum spacing is governed by the dimensions of major equipment and minimum structural requirements. The powerhouse is divided into seven structural bays separated by contraction-expansion joints above elevation 217 feet. The main units are spaced at 78 feet on centers, longitudinally. Reinforced-concrete vaults house the power transformers between the units.

The erection bay is located at the downstream end of the plant near the access tunnel. This arrangement resulted in practical and more effective handling of all mechanical and electrical equipment.

First-stage construction included the substructure, main floors, and walls, thus allowing early erection of the two 200-ton bridge cranes for installation of the main equipment as well as for the future operation and maintenance of the plant.

The powerhouse structure has the following functional space allocation: generator room, switchgear gallery, turbine floor, access and high-voltage galleries, transformer vaults, valve pits, service bay, and space for general station operation facilities. The control building is located near the toe of the Dam adjacent to the switchyard. Control and high-voltage cables are extended to the control building and switchyard in galleries traversing the powerhouse and access tunnel. The draft-tube gates are operated from the machine hall through gate slots at the downstream wall of the plant.

Steel spiral casings are fully embedded in concrete. Ample working space around and below the liner was provided in the first stage of concrete construction to facilitate its erection, welding, field testing, and placement of reinforcing.

Location of Transformers. Underground powerhouses require special economic studies related to the problems associated with the electrical installations. The necessity for placing the switchyard aboveground creates a situation where the distance between the main generator and the switchyard is usually much longer as compared with surface power plants. This means that the energy must be transmitted from the generators to the switchyard, either by means of long high-voltage cables or low-voltage leads.

In Edward Hyatt Powerplant, the power transformers were placed in concrete vaults located between the units. High-voltage cables placed in an 8- by 8-foot gallery transmit the energy to the switchyard. This particular arrangement was adopted on the basis of economics, which depends basically on the cost of additional underground space required for the transformers and high-voltage cables (including the cables themselves) versus the cost of a low-voltage leads-type installation.

The main control room is in the control building aboveground at the switchyard, and the control cables extend through the entire length of the access tunnel to the Powerplant. The high-voltage-cable tunnels that contain both the control and the high-voltage cables are described later in this chapter.

Powerhouse Access and Other Required Tunnels

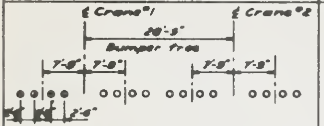
Powerhouse Access Tunnel. The powerhouse access tunnel provides access to the underground machine hall. The tunnel is approximately 1,510 feet long on an upward grade of approximately 6% from the powerhouse generator floor (elevation 252 feet) to the tunnel portal (elevation 340 feet). The tunnel is concrete-lined at the arch and walls, and the invert is paved with 8 inches of concrete over a layer of drain material. In addition to providing access to the machine hall during construction and operation, it is also a passage for cables from the units to the switchyard.

Concrete for tunnel lining was designed for an ultimate strength of 5,000 psi in one year. The one-year strength was specified as full loads were not carried by the lining until the reservoir was filled. Concrete for cable gallery partitions and portal structure for the access tunnel was designed for ultimate strength of 3,000 psi in 28 days. Reinforcement steel, Nos. 3 through 11, conforms to ASTM Designation A15, Intermediate Grade; No. 14S conforms to A408; and No. 18S conforms to A432.

The access tunnel finish lines were required to contain two cable galleries, approximately 8 feet by 8 feet, and the largest piece of powerhouse equipment (transformer) on its carrier. A 25-foot tunnel width satisfied this criteria by leaving an access passage width of approximately 16 feet after deducting the room required for the cable gallery and concrete parti-

SPECIAL LOADS

POWERHOUSE CRANE - 200 TON



Two 200 ton bridge cranes
Span = 64'-6"
Max wheel load = 62 kips
Crane weight = 183 kips.
Trolley weight = 80 kips.
Impact = 10%
Long. thrust = 10% of wheel load
Lateral thrust = 10% of hook load plus trolley weight.

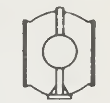
LOADING CONDITIONS

1 Dead loads
2 Equipment erection loads at designated area
3 Alternate live loading on floors
4 Uplift and side water pressure in powerhouse based on maximum tailwater elevation of 2##.0.
5 Backfill: horizontal pressure determined by the character of the backfill material.
6 Earthquake forces in powerhouse based on 0.1g
7 Earthquake and wind forces in all structures, except powerhouse, in accordance with the 1964 Uniform Building Code.
8 Temperature variation loads (± 40°).
9 Crane loads and thrusts
10 Pressure in spiral case during placing of concrete = 250 psi.
11 Maximum water pressure in spiral case under water hammer conditions = 380 psi
12 Pressure in spiral case during field loading = 450 psi.
13 Hydraulic thrust plus weight of turbine rotor parts =
14 Thrust from each servomotor = 395,000 ft lbs.
15 Maximum torque to be transmitted to generator foundation = 2,244,125 ft. lbs

ALLOWABLE DESIGN STRESSES

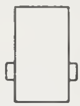
Concrete: $f_c = 0.45 f'_c = 0.45 \times 3{,}000 = 1{,}350$ psi
Reinforcement: $f_s = 20{,}000$ psi.
Structural steel will conform to ASTM designation A36 except as noted

SPHERICAL VALVE



Wt = 300 kips

TRANSFORMER

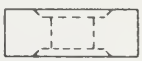


Wt. w/o oil = 206 kips
Wt. w/ oil = 325 kips

STATOR SECTION

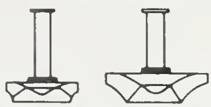
Generator = 111.7 kips
Motor-Generator = 101 kips

ROTOR



Generator = 555 kips
Motor Generator = 500 kips

RUNNER AND SHAFT



Turbine Runner wt. = 50 kips
Lower shaft = 58 kips
Motor Turbine: Runner wt = 185 kips
Lower shaft = 52 kips

MISC LOADS

LOADS

ELEV.	LOCATION	LIVE LOAD LBS/SQ.FT	SPECIAL LOADS	FLOOR FINISH
	POWERHOUSE			
	Units 1 to 8			
252.0	Generator floor	1000		1"
	Hatch covers	1000	Set down areas for erection of equipment shall be subject to approval of the Engineer	
234.0	Electrical gallery	500		
	Hatch covers	500		
227.0	Cable gallery roof	300		
217.0	Governor gallery	500		
	Hatch covers	500		
216.0	Transfromer floor	Unlim.		
	Unit 1	1000		
215.0	H.V Cable gallery	500		
1[illegible].0	Valve pit floor	Unlim		
1[illegible].0	Valve access gallery	Unlim		
	Stairs	100		
252.0 △	Air housing cover	100		
	Service Bay			
268.0	Elevator roof	300		1"
252.0	Service floor	1000		1"
	Rotor erection area	1000		
	Hatch covers	1000		
234.0	Batteryroom & shop	500		
	Hatch covers	500		
226.0	Cable gallery roof	300		
217.0	Pump room	500		
	Oil storage room	Unlim		
	Hatch covers	500		
198.0	Compressor room	500		
	Hatch covers	500		
1[illegible] 0	Machine room	Unlim.		
	Elevator lobbies	200		
	Stairs	100		
	Toilets	200		1½"
	CONTROL BUILDING			
	Roof	12		
	First floor	200		Varies
	Basement	Unlim		
	ACCESS TUNNEL ENTRANCE & AIR INTAKE BUILDING			
362.0	Roof	50		
350.50	Floor	300		
370.0	Roof	50		
	HIGH VOLTAGE & CONTROL CABLE TUNNELS			
347.0	Roof Sta 20+33.03 to Sta 20+67.24	300		
347.5	Roof Sta 21+01.24 to Sta 21+80.00	1,000		
	Sta 22+42.00 to Sta 28+24.50			
347.0	Roof (under road)		H 20 - S 16	
347.0	Roof	200		
350.0	Roof	200		
	EMERGENCY GENERATOR VAULT			
350.0	Roof	200		

Figure 68. Powerhouse Loads

tion. A height of 15 feet - 4 inches was required from the floor to the tunnel springline to meet the above requirements. This size allowed two lanes of traffic for haulage during construction of the plant before the concrete lining was placed.

For approximately 140 feet at the tunnel portal, structural steel support was designated. A support system using W10X49 ribs spaced at 4 feet resulted from a design rock load equivalent to ½ bore width in height. The remainder of the tunnel was supported with structural steel supports or rock reinforcement.

External hydrostatic pressures on the lining were assumed to be much lower than maximum possible ground water pressure as portions of the tunnel are within the zone of influence of the powerhouse drainage system and, as described later, much effort was put into draining water outside of the section. The tunnel lining was designed for an external head of 90 feet (approximately 25% of ground water) around the arch and varying linearly down the wall from 90 feet at the springline to zero at the invert. Dead load of the lining and partition frame loads also are included in the analysis.

As the access tunnel does not intersect the dam cutoff curtain and the rock conditions are quite good, no consolidation grouting was assumed necessary. Pipes were placed in the lining at the soffit of the tunnel to contact grout the voids between the lining and rock. This was done at quite low pressures (30 psi maximum) with a sanded grout.

To minimize external hydrostatic loading on the concrete tunnel lining, an elaborate drainage system was incorporated into the tunnel section. Twenty-five-foot-long drain holes were drilled through the lining into the rock and spaced at 20 feet longitudinally. Two were placed in the arch and two in the straight wall portion. The tunnel invert is a free-floating concrete slab on a layer of graded drain material. Perforated concrete pipes, 8 inches in diameter, were placed below the floor at each side of the section to convey drainage to the "moat" surrounding the powerhouse. A small gutter with holes to the concrete pipe is located on the left side of the section to allow drainage water from inside the tunnel to escape. In an effort to keep the cable galleries as dry as possible, plastic pipes were placed in the drain holes on the outside wall which convey drainage directly to the invert pipes.

An 8-foot by 8-foot gallery tunnel at floor level houses the six high-voltage cables. Above this gallery, a partition extends to the tunnel ceiling providing a gallery for the control cables. The high-voltage-cable gallery begins at the intersection of the high-voltage-cable tunnel, approximately 500 feet from the machine hall, and extends to the switchyard.

The control-cable gallery was excavated beneath the access tunnel floor for a distance of 100 feet from the powerhouse, so that the full width of the tunnel adjacent to the powerhouse would be available as a working area. At this point, it rises vertically and enters the access tunnel along the north wall at a sufficient height to clear the high-voltage-cable gallery intersection. The space below the 100-foot portion of gallery between the vertical rise and the intersecting high-voltage gallery was enclosed to provide storage.

The high-voltage-cable gallery wall and ceiling are 8-inch-thick cast-in-place partitions. The frame is attached to the tunnel by welding studs to metal inserts and tying the partition reinforcement to these. The gallery ceiling is supported on a ledge which was constructed monolithically with the tunnel lining. Loading on the partition frame includes a uniform load of 200 pounds per square foot on the ceiling; three cables weighing 52 pounds per foot are cantilevered from the wall as dead weight. The wall connections are capable of resisting a pull of one-tenth the partition weight.

The control-cable gallery is enclosed by 8-inch-thick precast panels between the frame, described previously, and the tunnel ceiling. Metal inserts are provided for connection of the panels. These connections are capable of resisting a lateral force of one-tenth the panel weight.

The panels are loaded with six cable trays, weighing 35 pounds per foot, cantilevered from the lower half. Bending due to lifting also was considered.

High-Voltage-Cable Tunnel. The high-voltage-cable tunnel connects the cable gallery in the powerhouse with the access tunnel gallery. The tunnel leaves the southwest corner of the powerhouse (invert elevation 217 feet) on an incline, parallels the access tunnel, and connects to the access tunnel at floor level.

To maintain the cable tunnel as dry as possible, a concrete tunnel lining was placed, and a rubber waterstop was used at the junction of the powerhouse structure and the lining.

The high-voltage-cable tunnel excavation was enlarged by the contractor to permit hauling excavated materials from lower levels of the powerhouse resulting in a larger opening than the minimum required. A minimum concrete lining was added to carry the design loads adequately. In an effort to keep the tunnel as dry as possible, no drain holes were drilled through the tunnel lining for hydrostatic pressure relief. The tunnel is downstream of the dam grout curtain and partly within the zone of influence of the powerplant drainage system and is affected by drainage in the access tunnel. Thus, a reduced external hydrostatic head was assumed. A design head equal to 50% of the distance to ground surface was used in design.

For estimating purposes, a support capable of holding a rock load equal to one-half the bore width in height was used. This resulted in a 6-inch-deep beam spaced on 4-foot centers. Rock in the vicinity of the tunnel was of good quality and structural steel support was not required. Rock bolts and wire mesh were sufficient to reinforce the rock arch and take care of small fallouts.

Contact grouting at the crown filled all voids between the lining and the rock. A sanded grout was used for this purpose.

Emergency Exit Tunnel. The emergency exit tunnel connects the river outlet access tunnel with the grout gallery under the Dam. It provides a means of escape from the powerhouse in addition to the powerhouse access tunnel. It also provides convenient access to and escape from the core block. The tunnel is an 8-foot-diameter, concrete-lined, circular section. The invert has a 6-inch-thick, flat, concrete walkway. The floor is roughened to provide a nonskid surface.

The tunnel passes over Diversion Tunnel No. 2 and the valve air supply tunnel. An 18-inch-diameter, vertical, drain hole is provided from the emergency exit tunnel to the air supply tunnel. This drains leakage into the tunnel and is an additional means of draining the core block by pumping water up to the grout gallery intersection.

Concrete for tunnel lining was specified to attain an ultimate strength of 4,000 psi in 28 days. Reinforcement steel conforms to ASTM Designation A15, Intermediate Grade.

As the tunnel is in good rock, only minimum rock support with rock bolts was required.

The 1-foot-thick concrete tunnel lining is capable of resisting the external hydrostatic head of the full reservoir while providing sufficient room for convenient placement of concrete. Nominal steel reinforcement was used on the inside surface to preclude excessive cracking.

River Outlet Access Tunnel. The river outlet access tunnel connects the valve chamber in Diversion Tunnel No. 2 with the northern end of the powerplant machine hall. As described above, this tunnel serves as a portion of the access route between the powerhouse and grout gallery. This is described in Volume III of this bulletin.

Control Building, Switchyard, and Appurtenances

The main control building and switchyard are located aboveground near the entrance to the access tunnel at the downstream toe of the Dam. This location was selected to keep the high-voltage cables and tunnels as short as possible.

Control Building. This facility, the Oroville Area Control Center, is the primary operating and dispatching center for both Edward Hyatt and Thermalito Powerplants and for all the hydraulic appurtenances in the Oroville project area.

This building is a one-story reinforced-concrete structure with basement. The basement is the cable-spreading area and provides entry to the high-voltage and control-cable tunnel. The first story is the main floor and contains the control room and a visitors area. The visitors area is separated from the control room by a glass partition to allow public viewing of the operations.

High-Voltage and Control-Cable Tunnel. The high-voltage and control-cable gallery in the access tunnel extends beyond the powerhouse access tunnel as a double-barreled, reinforced-concrete, cut-and-cover tunnel that enters the basement of the control building in the vicinity of the cable-spreading area. The cut-and-cover tunnel also extends from the control building along the centerline of switchyard and serves as the foundation for the takeoff towers, lightning arrestor supports, and pothead supports.

Special precautions were taken to eliminate the possibility of induced current heating the reinforcing bars in the vicinity of the pothead supports and cracking the slab. Waterstops were provided at all transverse expansion and construction joints to waterproof the tunnel. Also, polyvinylchloride sheeting was bonded to the exterior face of the tunnel walls and to the top slab wherever they were below grade.

Switchyard. The switchyard is located approximately 1,500 feet southwest of the underground powerhouse at elevation 350 feet. The takeoff towers and supports were designed as dead-end towers (combination of broken wire and intact assumptions). Live loads are a horizontal tension of 6,200 pounds and vertical force of 800 pounds. Takeoff towers were constructed of 20- by 20- by ⅜-inch structural steel plates. The structural supports were spaced in accordance with electrical safety requirements.

The emergency generator vault for a 500-kW, emergency, engine-generator set was constructed of reinforced concrete. The electrical equipment foundations include both the spread footing and the drilled cast-in-place types of footings. In addition, some foundations were anchored to rock where feasible. All cast-in-place-type footings were designed for a maximum toe pressure of 4,000 psi and a factor of safety of 1.5.

To ensure a lesser portion of any precipitation infiltrating the soil, all compacted backfill was capped with an impervious layer of backfill. To handle the water that does infiltrate the soil, underdrains are provided around the high-voltage and control-cable tunnel and the emergency generator vault.

Mechanical Features

General

The mechanical installation includes three turbines and three pump-turbines, turbine shutoff valves, governors, cranes, plant auxiliaries, and intake equipment.

Chapter I of this volume contains information on the mechanical equipment and systems for the Powerplant which are common to other plants in the State Water Project. Information and descriptions which are unique to this plant are included in the following sections.

Plant Capacity and Operating Conditions. Plant capacity in terms of dependable power was established following a series of operational studies of Lake Oroville and the Hyatt-Thermalito power features (Figure 59). Basically, power development was integrated with the multipurpose function of the reservoir, meeting the requirements for flood control, downstream flow, water demands, fish preservation, and recreation.

After investigation of the economics, reliability of operation, flexibilty, and performance of the units, the dependable capacity for Edward Hyatt Powerplant was established initially at 600 megawatts (MW) with Lake Oroville theoretically drawn down to a minimum power pool of approximately 1.5 million acre-feet. Plant capacity above minimum power pool was dependent upon the available head but was normally limited by the ratings of the electrical machines or to 115% of nameplate capacity under certain conditions.

Total pumping capacity was based on providing pumpback during off-peak hours to provide sufficient water to generate during on-peak hours at not less than 34% capacity factor to meet the anticipated load requirements. Off-peak hours were in accordance with a coordinated schedule agreed upon with the utility companies.

In 1963, continuing studies were performed to optimize the dependable capacity of Edward Hyatt and Thermalito Powerplants without overloading or changing design. The previously determined dependable capacity of 685 MW was based on the sum of the individual capacities of the two plants (Hyatt and Thermalito) as separate entities. Since Hyatt has the ability to produce more than 600 MW under conditions which limit Thermalito to its dependable capacity and, conversely, Thermalito capacity can be increased under conditions which limit Hyatt to 600 MW, the combined output of the two plants is always greater than the sum of the individual minimums. As a result, the combined dependable capacity was established at 725 MW at a capacity factor of 34% and the power was marketed as if from a single plant. This is discussed in Volume I of this bulletin.

Selection of Units. As a result of the water studies and based on the poorest series of water years of record, 1928 through 1934, it was apparent that, with the available off-peak hours, an approximate pumpback capacity of 5,600 cubic feet per second (cfs) would be required at Hyatt to maintain the dependable capacity. The units would operate through a head range of 500 to 660 feet, which represented the full pumped-storage operating range of the reservoir. To keep the physical size of the units within reasonable limits, in accordance with manufacturing capabilities and the designs developed at that time, three pump-turbine units were chosen to fulfill the pumping cycle requirements.

Once the pumping requirement was established and it was determined that each pump-turbine unit would have a generating capability of 120,000 horsepower (hp) at minimum power pool, three turbines were selected to complement the pump-turbines and provide the required plant capacity. This selection provided a very close match in physical size with the pump-turbines, allowed construction of uniform bays in the plant, and permitted selection of shutoff valves of common size. To further simplify powerplant design, a common setting for all units at elevation 205 feet was specified providing a minimum submergence of 19 feet at the centerline of the distributor.

Hydraulic Transients

Conduits and Waterways. Plant facilities include two intake structures with water-temperature control shutters, two 22-foot-diameter penstocks, and a tailrace system consisting of two 35-foot-diameter tunnels approximately 2,000 feet long (Figures 69 and 70).

The tailrace is a modification of the two Oroville Dam diversion tunnels formed by interconnecting the tunnels with the draft tubes and plugging the tunnels upstream of the units. Tunnnel No. 1, which has an inclined upstream section, is below tailwater elevation for most of its length and operates as a pressure conduit. Tailrace Tunnel No. 2 flows a little over half full at a normal tailwater elevation of approximately 226 feet. At the upstream end of Tunnel No. 1, near the tunnel plug, there is a free surface interconnected with Tunnel No. 2 by an equalizing air vent. The tunnel volume above this free surface and the upstream portion of Tunnel No. 2 acts as a surge chamber for pressure flow in Tunnel No. 1 and provides necessary storage volume during load fluctuations.

Design Criteria. Hydraulic transient criteria were:

1. Simultaneous rejection of 115% of rated generating load of all six units at maximum head of 675 feet.
2. Simultaneous rejection of rated load of all six units at a head of 500 feet.
3. Power failure at any pumping capacity with the governors inoperative.
4. Load acceptance at rate of 100 MW/minute.
5. Speed rise limited to approximately 45%.

Penstocks and Intakes. The penstocks were designed for the maximum static head plus a water-hammer pressure of 30%. Design computations indicated that the maximum transient pressure under the above critical conditions would not exceed 25%. Calculations were based on a governor time of 7 seconds for the turbines and 20 seconds for the pump-turbines with an expected maximum speed rise of 45% for the turbines and pump-turbines.

With temperature control shutters installed, the intake structures (Figure 64) act as an extension of the penstocks and are, therefore, subject to similar overpressures and underpressures during hydraulic transients. Studies included determination of the required relief areas to reduce the loads on the shutters during load acceptance and rejection.

Computations for water hammer were performed by the graphical method developed by Schnyder and Bergeron, as well as by the method of arithmetic integration. Because at the time of design the reversible pump-turbine was just being introduced into the hy-

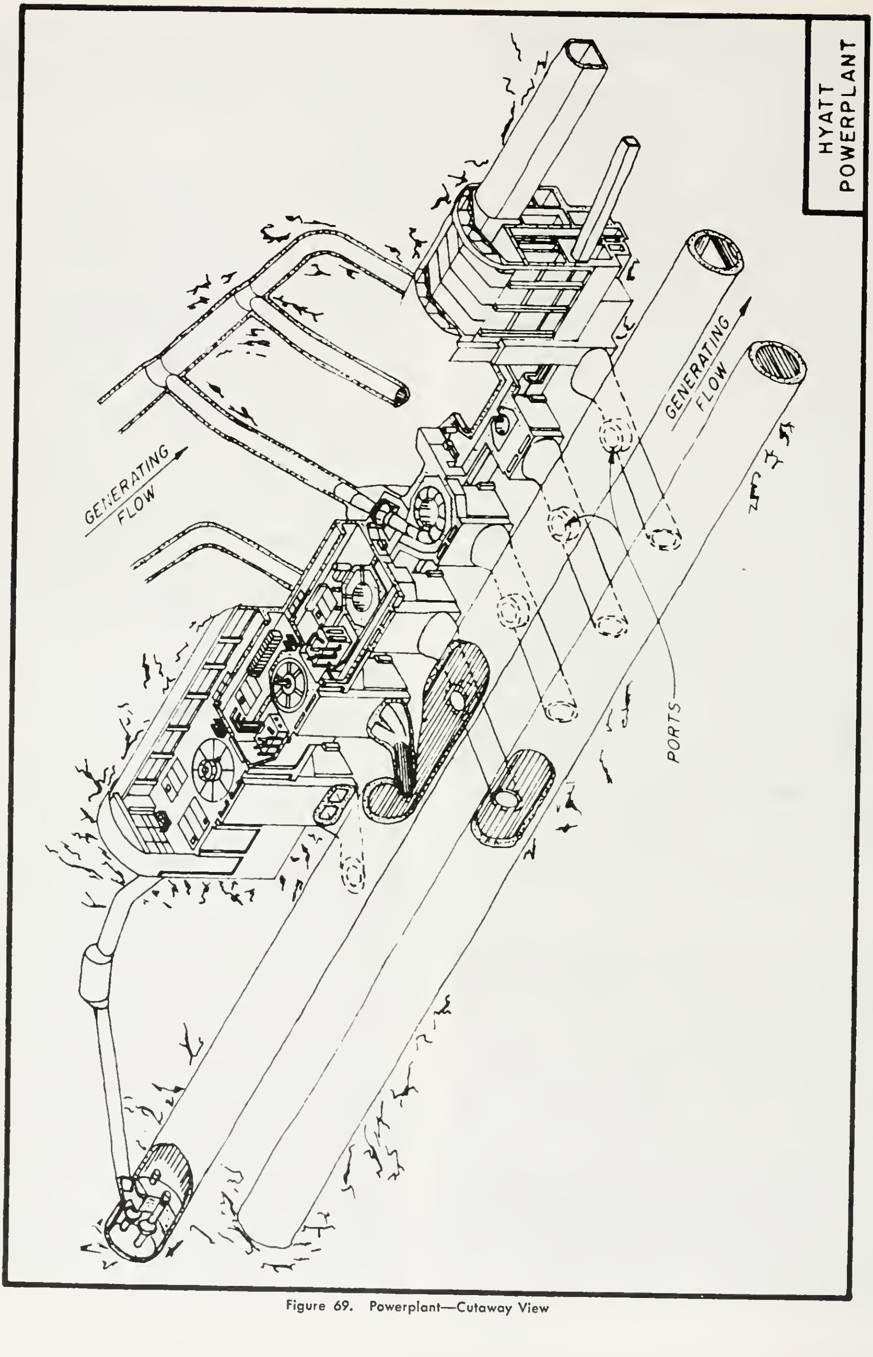


Figure 69. Powerplant—Cutaway View

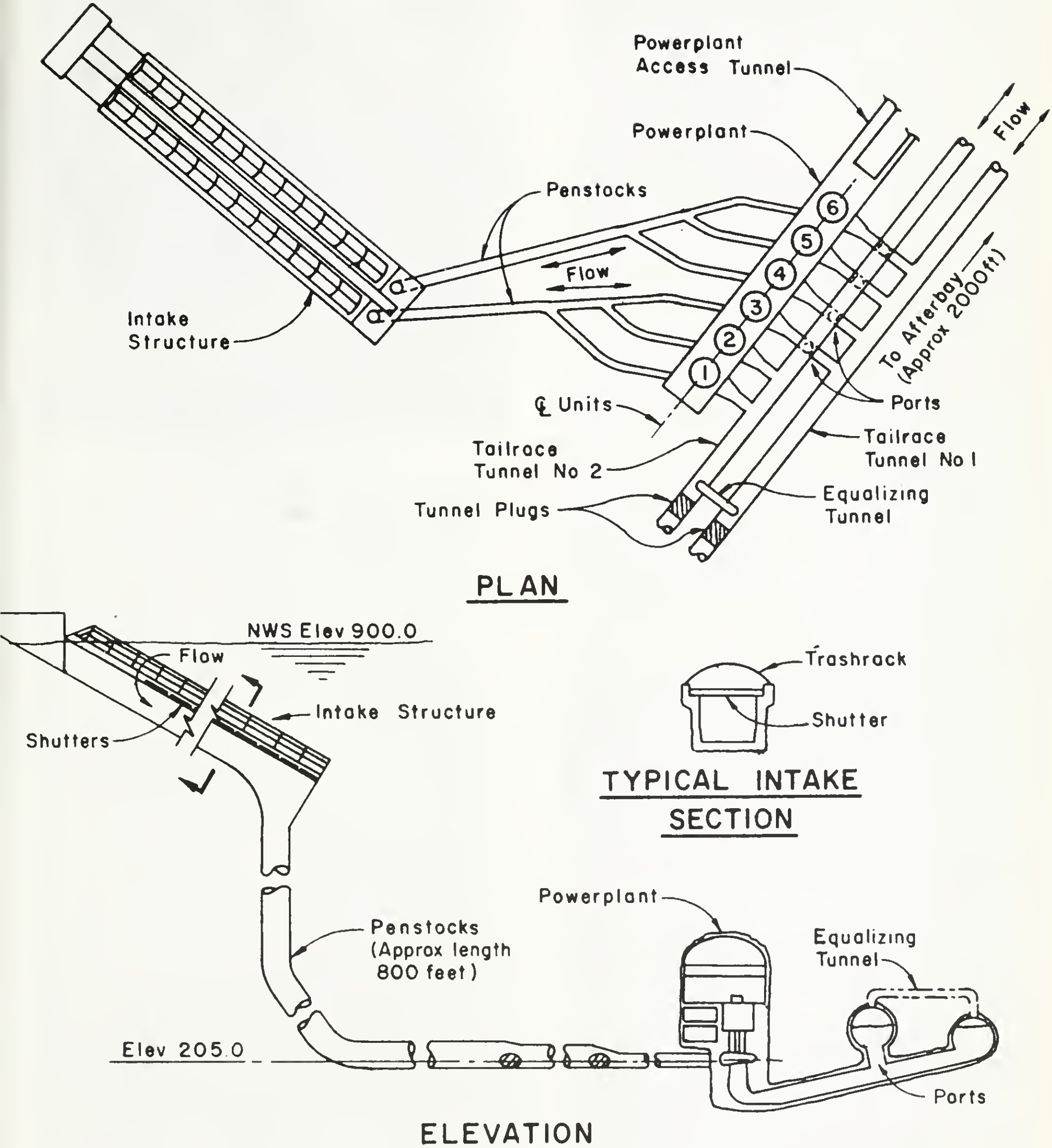


Figure 70. Powerplant and Waterways

droelectric field, complete characteristic (quadrant) curves were scarce for units similar to those planned for Hyatt; it was therefore necessary to synthesize some basic data by similitude relationships from turbines and pumps of appropriate specific speeds.

Tailrace. The tailrace system was designed to accept the hydraulic transients associated with total plant load rejection at 115% generator capacity and power failure with maximum pump capacity. Economics limited the size of tunnels and thereby the load acceptance rate to approximately 100 MW/minute. The flow wave associated with the most rapid and simultaneous load acceptance of the six units would cause the tailrace to top out imposing excessively high shock pressures on the downstream side of the units. Consequently, special interlocks were provided to limit the rate of load acceptance.

Transient phenomena produced by rapid load changes involved problems of both mass oscillation and free surface wave propagation. Although investigation indicated no problem in controlling the magnitude of downsurge following load rejection, there was concern about a possible in phase return of the mass surge in Tunnel No. 1 with an advancing surface wave in the open channel of Tunnel No. 2. Superposition of these phenomena could cause Tunnel No. 2 to top out and, similar to the case of a too rapid load acceptance, produce a pressure rise that would be transmitted directly to the units. Because of the destructive potential of such a shock wave, provision against its occurrence had to be assured.

The design was subjected to exacting analytical studies. Since none of the existing methods of solution for translatory waves in open channel was applicable to the complex tailrace problem, a technique was devised by combining the graphical procedure developed by Professor A. K. Schoklitsch for mass surge with the numerical computation method of R. D. Johnson for wave propagation. The analytical results proved the system design conservative. Subsequent model studies performed under contract at the laboratories of the U.S. Bureau of Reclamation in Denver further established the validity and conservatism of the analysis.

Hydraulic Transient Tests. Field tests to verify that the system operated as designed were performed successfully in June 1969. A load rejection of 768 MW (approximately 15,200 cfs) under a static head of 673 feet produced a penstock pressure rise of 23% above static head; conversely, power failure simulation of 241 MW during pumping (approximately 2,550 cfs) produced a maximum penstock pressure drop of 18%. The maximum speed rise upon full load rejection in the generating mode was 41% and 42% for the turbines and the pump-turbines, respectively. All equipment and all hydraulic features functioned satisfactorily when subjected to the most adverse emergency conditions in either mode of operation.

Equipment Ratings

Turbines (Units Nos. 1, 3, and 5)

Manufacturer:	Allis-Chalmers Manufacturing Company
Type:	Francis
Horsepower, each:	161,000 @ 500 feet
Head (weighted average):	615 feet
Speed:	200 rpm
Manufacturer's Guaranteed Efficiency:	94% w/161,000 hp @ 615 feet

Pump-Turbines (Units Nos. 2, 4, and 6)

Manufacturer:	Allis-Chalmers Manufacturing Company	
Type:	Modified Francis	
Horsepower, each:	120,000 hp @ 500 feet	
	Turbine Mode	*Pump Mode*
Discharge, each:	———	1,870 cfs
Head (weighted average):	615 feet	592 feet (rated)
Speed:	189.5 rpm	189.5 rpm
Manufacturer's Guaranteed Efficiency:	91.6% w/120,000 hp @ 615 feet	92.4% w/1,870 cfs @ 592 feet

Valves

Manufacturer:	Baldwin-Lima-Hamilton Corporation.
Type:	Spherical, double-seated
Size:	114 inches
Design Pressure:	400 psi
Operating Time:	4 minutes
Hydraulic System Pressure:	1,000 psi

Governors

Manufacturer:	Baldwin-Lima-Hamilton Corporation.
Type:	Cabinet-actuator
System Pressure:	350 psi
Servo Capacity:	385,000 ft-lbs
Full Gate Stroke	
Turbine:	9 sec./3 sec. cushion
Pump-Turbine:	22 sec./3 sec. cushion

Cranes

Manufacturer:	Star Iron and Steel Company, Tacoma, Washington
Type:	200-ton, powerhouse, bridge-crane
Rated capacity, each tons:	200
Rated capacity of each of 4 main hoists, tons:	100
Rated capacity of each of 4 auxiliary hoists, tons:	20
Span:	64 feet - 6 inches

Turbines and Pump-Turbines

Three turbines and three pump-turbines were installed in the underground plant. The turbines are the vertical-shaft Francis type and are directly connected to synchronous generators operating at 200 rpm. The pump-turbines are the vertical-shaft modified-Francis type and are directly connected to motor generators operating at 189.5 rpm (Figure 71).

The runners have stainless-steel overlay for protection against cavitation and were designed to allow removal through the generator and motor-generator stators by the powerhouse crane.

Figure 71. Turbine Pit

The pumping units are started with the water depressed below the runner. Both turbines and pump-turbines can be utilized to allow the electrical machines to operate as synchronous condensers.

Major Design Modifications (Turbines and Pump-Turbines)

Headcover Design. During the Department's review of the manufacturer's design of the pump-turbines, reports from other projects were received indicating serious problems with the headcovers of similarly sized units. Some headcovers had deflected excessively, causing binding of the wicket-gate stems. These difficulties could be even more pronounced in the Hyatt units due to the specified requirement that the headcovers be divided into inner and outer sections to permit removal of the runner through the motor-generator stator bore without disassembly of the wicket gates.

At the time of the review, there were two generally accepted techniques available for the stress and deflection analysis of headcovers. These were (1) the Ruud method developed at the U.S. Bureau of Reclamation in Denver, and (2) the Kovalev method of the Leningrad Metallurgical and Machinebuilding Works. Both methods idealize a headcover as a torus consisting of the ring sections only. The interconnecting ribs are assumed to be sufficiently rigid to constrain the structure cross section to twist through a uniform angle about the centroid of the ring sections. These methods were utilized in the Department's initial review of the manufacturer's proposed design.

Shortly thereafter, a new analysis tool developed by Dr. Clough of the University of California and used extensively in the design of the powerhouse rock excavation became available. This new computerized Finite Element technique was subsequently modified for the analysis of headcover-type structures. In the Finite Element idealization, the headcover cross section is represented as an assemblage of discrete elements interconnected at corner nodal points. This provides a more realistic representation of the structure stiffness than that obtained in the Ruud or Kovalev methods.

The first Finite Element analysis of the proposed headcover design revealed areas of excessive stress and deflection considerably different from the Ruud and Kovalev results. With the concurrence of the manufacturer, this new method was then used to determine the size and location of additional structural material needed to bring the stresses and deflections within allowable limits.

Stress and deflection measurements made in field tests on an operating pump-turbine substantiated predictions made in the computerized analysis. Following these pioneering efforts, the basic method was adopted in the United States and elsewhere by leading manufacturers of hydraulic turbines and pump-turbines.

Runner Uplift and Downthrust. During the design and fabrication of the Hyatt pump-turbines, experience during start-up with similar-type units at other installations indicated that excessive uplift and downthrust forces on the runner could occur under certain operating conditions. To prevent this, the pump-turbines were modified to balance the pressures on the top and bottom of the runner by the use of a 12-inch equalizing pipe connecting the top and bottom chambers. No excessive uplift or downthrust has been detected since the units have been in operation.

Wicket-Gate Restraining Mechanism. The accepted practice in the design of turbine gates and gate mechanisms provides a shear pin to release individual wicket gates in the event of jamming. At several installations, severe damage had occurred due to violent oscillations and subsequent cascading failure of the wicket gates after shearing of one or more wicket-gate pins. To prevent this problem, gate restraining mechanisms were provided for all units. These mechanisms consist of a series of Belleville springs mounted on the wicket-gate levers to provide a controlled frictional restraining action after shearing of the pin. Proper design and accurate adjustment of the restraining device were required for reliable operation.

Runner Imbalance. The size of the pump-turbine runners required a two-piece design for shipping and handling (Figure 72). To reduce the turbulence that would be created by the protruding flanges, the space between the flanges was shrouded with steel fairing plates. After several months of operation, Unit No. 4 developed excessive runout due to imbalance caused by water leaking into some of these cavities. A short time later, Unit No. 2 developed a similar imbalance. Several methods were tried by the manufacturer to balance the runners in place without complete suc-

Figure 72. Runner Shaft Assembly

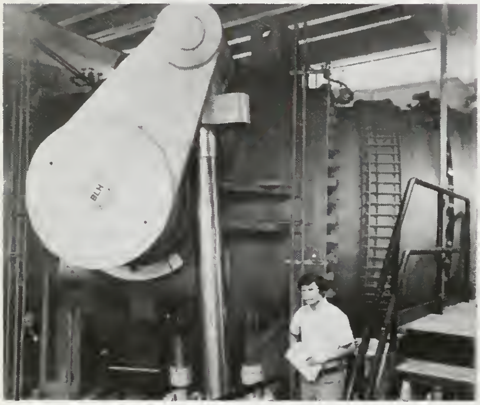


Figure 73. Spherical Valve—Side View

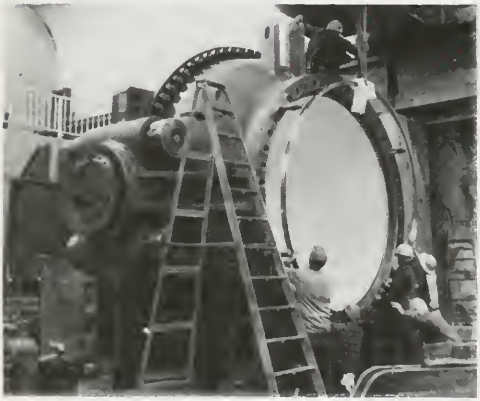


Figure 74. Spherical Valve—Angle View

cess. The final solution that evolved required drilling openings to all cavities so that water could enter freely and equally around the runner. This has proven to be a satisfactory solution.

Turbine Shutoff Valves

Each unit is provided with a 114-inch shutoff valve (Figure 73). They are spherical-type, double-seated, hydraulic cylinder-operated and were designed to sustain the maximum transient pressure without exceeding allowable design stresses. The valves have a 1,000-psi electrohydraulic actuating and control system. Each seat is separately controlled and operated by water from the pressure side of the valve (Figure 74). The valve and controls are designed for normal opening and closing and for emergency closure under full head (Figures 75 and 76).

During the early design stage, the Department recognized that special precautions against flooding would have to be incorporated in the design of this major underground plant. The state-of-the-art design precedent did not provide adequate safeguards, thereby leading the Department to design an appropriate operating system with as many fail-safe features as practicable. This special design included an automatic sequencing unit with feedback and interlock features to avoid operator error. Numerous provisions and back-up devices were installed to prevent accidental opening of the valve seats during the construction period and periods of maintenance when the downstream mandoor could be open. The more important of these provisions included:

1. Positive mechanical locks provided on all critical control valves.
2. Redundant, totally independent, pressure sources.
3. Pistons on the hydraulically actuated control valves, unbalanced to fail-safe.
4. Special removable safety loops in the control lines.

Figure 75. Spherical Valve Cantrol Cabinet

Figure 76. Spherical Valve Oil Pressure Tank

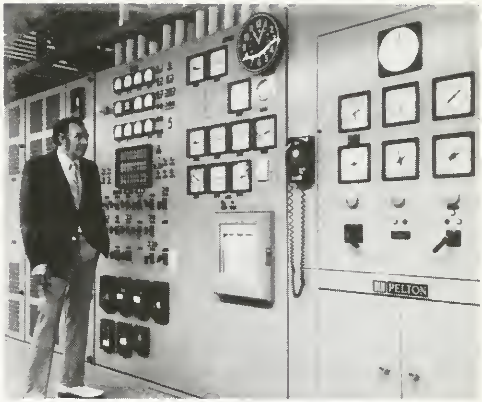


Figure 77. Governor Cabinet

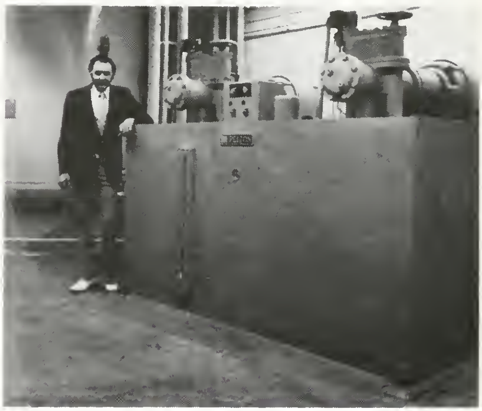


Figure 78. Governor Pumps and Oil Tank

Figure 79. Powerhouse Bridge Crane

Governors

Each unit has an electrohydraulic, oil-pressure, cabinet-actuator-type governor designed for speed regulation and control of turbines and pump-turbines (Figures 77 and 78). They are provided with an electrically driven speed responsive element directly connected to the pilot valve for actuation of the main oil-distributing valve.

The governors on Units Nos. 1, 3, and 5 are equipped with a third, reduced-frequency, shutdown solenoid for starting the motor-generators in the pumping mode. Also, the permanent magnet generators have two fields (one for 60-hertz operation and the other for 30-hertz) to permit governor control at either of these frequencies.

Equipment Handling—Cranes

The plant has two 200-ton bridge cranes for installation and maintenance of plant equipment (Figure 79). The two cranes are identical except for a draft-tube gate hoist monorail. Each crane has two trolleys with a 100-ton main hoist and a 20-ton auxiliary hoist on each trolley. They are used for installation and maintenance of generators, motor-generators, turbines, pump-turbines, penstock valves, transformers, and miscellaneous powerplant equipment. Both cranes operate on the same runway.

The cranes can be operated individually or can be mechanically and electrically interlocked for dual operation, as required, for lifting the spherical valves, the turbine and pump-turbine runners and headcovers, transformers, and the 387-ton generator rotors. During this latter operation, the cranes are linked together to ensure complete unity of movement.

A monorail support frame for the draft-tube gate hoist is bolted to the right-hand girder of one crane. A matching fixed monorail at each gate permits a single hoist to place or retrieve all draft-tube gates.

Space limitations in the underground powerhouse dictated the need for special handling devices to permit installation of the major equipment components. Accordingly, manufacturers of this equipment furnished the associated lifting devices for handling their equipment.

Capacities, travel, and speeds are as follows:

	Rated Capacity	*Nominal Speed*	*Travel*
Main Hoist	100 tons	4 feet per minute (fpm)	64 feet
Auxiliary Hoist	20 tons	20 fpm	90 feet
Bridge	200 tons	60 fpm	480 feet
Trolley	100 tons	30 fpm	40 feet

Auxiliary Service Systems

The auxiliary service systems in the plant are detailed in Chapter I of this volume with the following exceptions:

Raw Water System. The raw water system supply is taken from the penstocks through a three-step pressure-reducing set to bring the pressure down to acceptable levels (Figure 80). A pressure-reducing set is provided at each unit and consists of a motorized cone valve, a pneumatically controlled pressure-reducing valve, and a manually adjusted cone valve. These valves reduce the pressure in successive stages with the motorized valve providing shutoff service for the system when the associated unit is shut down. The pneumatically controlled reducing valve is required to maintain a constant level of system pressure through a wide range of flows since the flow rate is a function of reservoir water temperature and unit load.

Various schemes were studied for the refrigeration system, chilled-water piping systems, and the air-distribution system.

1. Refrigeration System—Consideration was given to using reservoir water from the penstocks and the river outlet. It was decided to use refrigeration machines for the following reasons:

a. It was not possible to use water from the penstocks because of the selective temperature control which would provide relatively warm water during certain times of the year.

b. It was decided not to tap the river outlet conduit due to concern for plant and personnel safety.

2. Chilled Water Piping—Various piping schemes were studied, such as "two pipe reverse return", "two pipe direct return", "primary-secondary pumping system", and others. The "primary-secondary pumping system" was chosen for the following reasons:

a. It offers a degree of control difficult and costly to achieve with valves alone.

b. It permits constant flow through the coolers eliminating stratification problems inherent with throttling systems.

c. Hydraulic and heat transfer balance is obtained in conjunction with economical operation.

d. Total pumping horsepower is normally lower.

3. Air Distribution System–The following schemes of supplying fresh air to the powerhouse were studied:

a. Outside air from Tailrace Tunnel No. 1, exhausting through the cable tunnels and access tunnel.

b. Outside air from the access tunnel, exhausting through the cable tunnels.

c. Outside air from the high-voltage tunnel, ex-

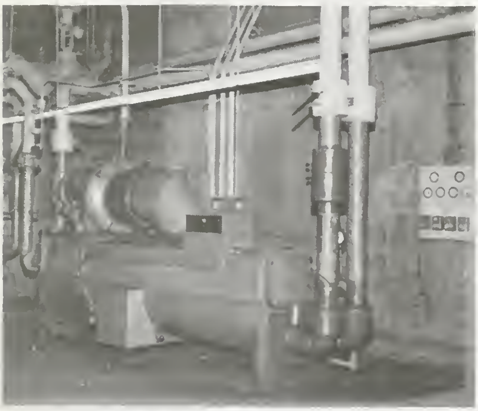


Figure 80. Raw Water System

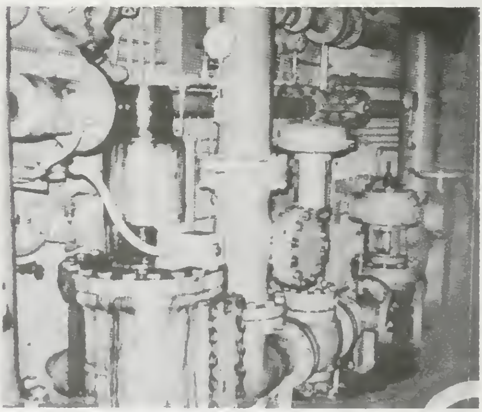


Figure 81. Air-Conditioning Refrigeration Compressors

hausting through the access tunnel and control-cable tunnel.

d. Outside air from the control-cable tunnel, exhausting through the access tunnel and high-voltage tunnel.

The last scheme was selected primarily due to the fallout protection requirement. It was decided to direct the air through the high-voltage tunnel and return it to the plant through the control-cable tunnel adding only a small amount of decontaminated air to pressurize the plant. Also, during normal operation, this scheme was judged superior since vitiated air is exhausted from the powerhouse through the access tunnel.

The raw water system provides cooling water for unit generator and transformer cooling, air-compressor cooling, domestic water, air-conditioning system cooling, sump-jet-eductor system, and fire-extinguisher system. There is a separate supply of cooling water for each of the six units and a single standby system designed to meet the needs of any one unit in event of failure of that unit's normal supply.

Air-Conditioning System. The air-conditioning system differs from the other plants. In addition to providing heating, ventilation, and cooling of personnel and maintaining the required ambient temperature for equipment, it also provides protection from radioactive fallout and cools the high-voltage tunnel and the transformer vaults. A primary-secondary pumping system was used to distribute the chilled water to the many zones required.

Preliminary design of the Powerplant was performed during the period when fallout shelters were being provided in many homes and business establishments. Since the underground plant made an ideal shelter, and it was judged essential to sustain power production during any emergency period, it was decided to provide the necessary equipment for fallout protection.

Automatic dampers and other equipment were provided to retain and recirculate air in the powerhouse and tunnels in the event of radioactive fallout in the area. In order to pressurize the powerhouse and tunnels and thus cause a slight exfiltration of powerhouse air, a relatively small amount of air is added to the system through a high-efficiency (fallout) filter.

The refrigeration systems consist of two high-speed, centrifugal, refrigeration machines (Figure 81). These machines are connected in parallel to chill water from approximately 56 degrees to 44 degrees Fahrenheit. Two centrifugal pumps circulate 800 gallons per minute (gpm) of water through the primary chilled-water circuit which extends the full length of the powerhouse and serves the seven fan-coil units and the main cooling coils. Secondary circuits at each coil provide a continuous flow of water at the proper temperature by means of secondary pumps.

Intake Structure Equipment

General. The equipment at the intake structure was designed for emergency and maintenance closure of the intake penstocks and selective water-level withdrawal from the reservoir to provide water temperature control. The intake gates are located at the lower end of the intake structures at the entrance to the penstock tunnels. A shutter gantry crane is provided to place and remove the shutters for selecting the level at which the water is drawn into the structure.

Intake Gates and Operator System. A 22-foot - 6-inch by 32-foot - 9-inch coaster-type gate at each of the two intakes is used for penstock closure (Figures 82 and 83). Gate speed is set to provide a five-minute emergency closure which may be initiated from the Oroville Area Control Center, the emergency control room in the powerhouse, or the intake structure control room.

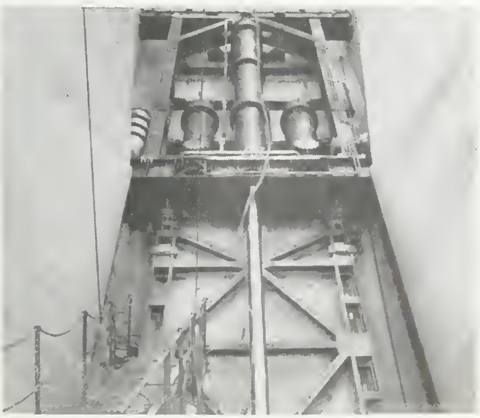


Figure 82. Intake Gate Operator

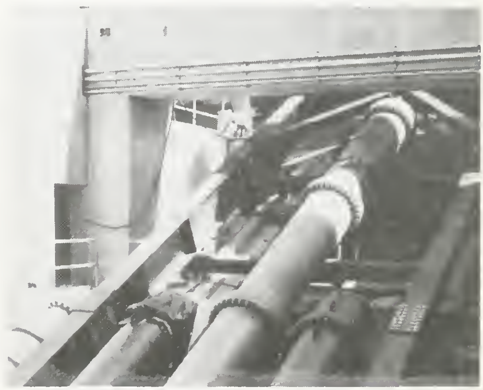


Figure 83. Intake Gate and Operator

The gate is a welded structural-steel assembly, fabricated in three sections with bolted joints. Continuous, stainless-steel, roller trains support the gate loads on embedded stainless-steel tracks in the intake structure. Seals are Teflon-clad double-stem type with a cam-operated pressurizing system.

A gate carriage supports the lower end of the gate when the gate and operator are transported within the intake structure. For testing in the operations and maintenance area, the carriage supports the full weight of the gate during stroking by the operator cylinder. The carriage also supports the gate in the event of emergency removal with the operator stem extended. The gate hydraulic cylinder operator is integral with its steel carriage and is directly connected to the gate. Latch bolts for rigidly securing this gate-operator carriage to the channel structure are provided. Both the latch bolts and hydraulic cylinder are remotely controlled.

Although gate model studies indicated continuous closing forces on the gate during emergency closure, a closing thrust of 300,000 pounds can be exerted by the gate-operator system if required. Each intake gate operator has two interconnected hydraulic systems mounted on the gate-operator carriage. Each system can close the gate independently if necessary. The hydraulic power unit and electrical system enclosures are pressurized with nitrogen to maintain a minimum operating pressure greater than the ambient water pressure. To assure maximum dependability, the hydraulic systems were initially cleaned to a high level of cleanliness and have filter elements to maintain this level. Power and control circuits for the gate operators are supplied through a 710-foot drag cable on a cable reel located in the operations area.

Precipitation-hardened stainless steel was used extensively in critical areas because of its range of physical properties and inherent corrosion resistance. This material has proved satisfactory in all applications where adequate precautions are taken to prevent galling and reasonable ductility is maintained through heat treatment.

Modifications. The following modifications have been incorporated in the intake gate and operator system:

1. The rollers on the gate-roller trains were changed from a fixed-roller-pin type to a free-pin type with bronze roller-pin bushings because of galling between the rollers and roller races when unloaded.

2. An automatic nitrogen-purge system was installed on the gate-operator hydraulic system to eliminate nitrogen gas accumulation at the rod end of the gate-operator piston.

Intake Gate Gantry Hoist. The intake gate gantry hoist lowers and raises the intake gates and operators along the sloping intake (Figure 84). It is rail-mounted and services both intakes. The hydraulically operated intake gate lifting beam is permanently connected to the gantry hoist and is controlled by an electrical drag cable connecting the lifting beam to the gantry hoist (Figure 85).

Shutter Gantry Crane. The shutter gantry crane transfers shutters to and from the storage bays and places or removes shutters from their submerged position in the intake structure (Figure 86). Two trolley hoists with a total of four hooks are used for shutter handling and intake structure general hoist service. A permanently attached shutter-lifting beam is connected to the crane's fixed hoist for placing and removing shutters.

Figure 84. Intake Crane Gantry Hoist

Figure 85. Intake Cranes

Figure 86. Shutter Gantry Crane

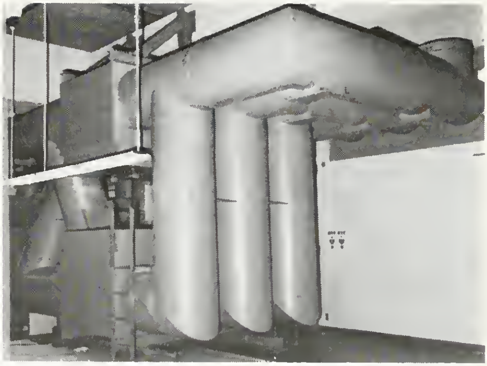


Figure 87. Iso-Phase Bus Reversing Switches

Electrical Features

General

The electrical installation includes the generators, motor-generators, power transformers, 230-kV oil-pipe-type cable, 230-kV switchyard, and the control and auxiliary systems. Descriptions of electrical systems which are common to other plants in the State Water Project are contained in Chapter I of this volume.

Description of Equipment and Systems

Electrical equipment and systems are generally of conventional design. Location of the powerhouse underground and starting of the motors required design and equipment deviations from normal practice.

A main-and-transfer bus arrangement was selected for the switchyard with three additional breakers installed for motor starting. Six bays are required for the power transformer connections and three transmission lines which terminate at the switchyard. Transmission lines connect to the Pacific Gas and Electric Company's Table Mountain Substation located approximately 9 miles from the switchyard.

Power transformers are located underground in vaults adjacent to the generator or motor-generator served. Connections from the switchyard to the transformers are made with 230-kV pipe-type cable. Generators and motor-generators are connected to the low-voltage windings of the transformers with isolated-phase bus. Bus connections to the motor-generators contain motor-operated switches for use in phase reversal for either motor or generator operation (Figure 87).

Station service supply is normally taken from a 230-13.8-kV transformer in the switchyard. Other supplies may be obtained from the generator bus at two locations in the powerhouse (Figure 88). Voltage is reduced to 480 volts for distribution to the various motor control centers, power distribution centers, and lighting distribution centers (Figure 89).

Figure 88. 15-kV Station Service Breaker

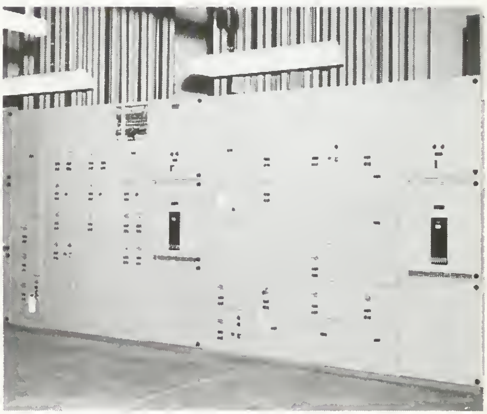


Figure 89. 480-Volt Station Service Distribution Board

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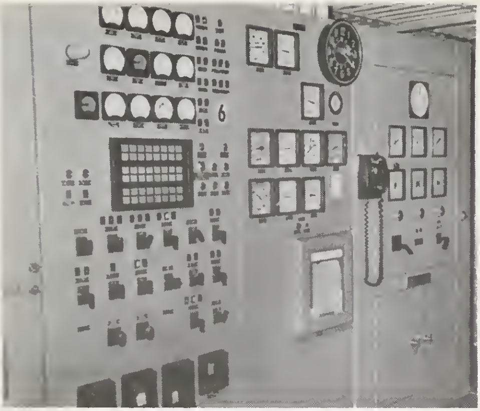

Figure 90. Unit Control Board

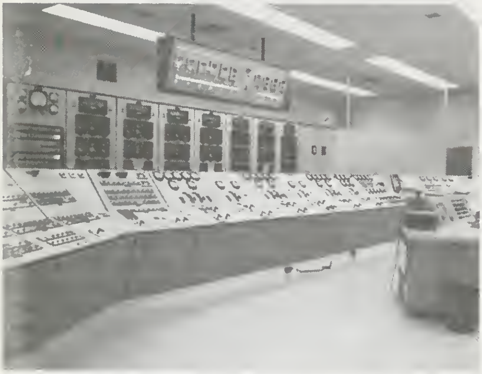

Figure 91. Control Room for the Oroville Complex

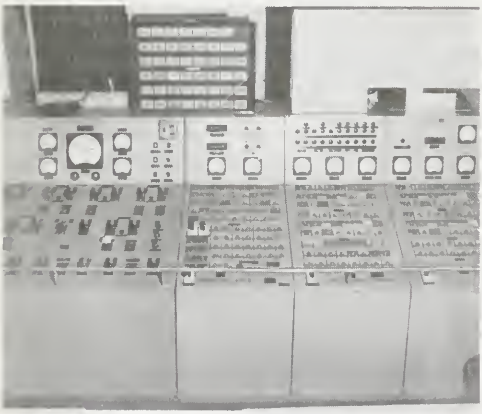

Figure 92. Emergency Control Board for Thermalito Powerplant

Switchboards were installed for each unit to house the protective relays, instruments, meters, annunciators, and operating controls (Figure 90). Control of the facility is normally from the control building near the switchyard (Figure 91); however, control of all functions also may be accomplished from equipment inside the powerhouse. Since operation of either the Hyatt or Thermalito plant depends on the other, an emergency control board and relay board were installed inside the powerhouse for controlling Thermalito Powerplant (Figures 92 and 93). This provides for continuity of operation during emergencies, including a nuclear disaster. Volume V of this bulletin describes the remote control systems and equipment.

Equipment Ratings

Generators and Motor-Generators

Manufacturer: Westinghouse Electric Corporation

Type: Vertical-shaft, synchronous, 3-phase, 60Hz

Generators Nos. 1, 3, and 5

Capacity: 123,157 kVA
Speed: 200 rpm
Power factor: 95%
Volts: 12,500

Motor-Generators Nos. 2, 4, and 6

Generating

Capacity: 115,000 kVA
Speed: 189.5 rpm
Power factor: 85%
Volts: 12,500

Motoring

Horsepower: 173,000
Speed: 189.5 rpm
Power factor: 100%
Volts: 12,000

Power Transformers

Number of transformers: 6
Manufacturer: Moloney Electric Company
Volts: 230-12kV, grounded-wye
Taps: In the high-voltage winding, 2½ and 5% above and below 230 kV
Phase: 3
Frequency: 60 Hz
Capacity: 127,000 kVA
Type: FOW
Transformer connections: Wye-Delta

Station Service Transformers

Substation Transformer

Manufacturer: Moloney Electric Company
Volts: 230-kV, grounded-wye, high-voltage—12.6-kV delta tertiary—13.8-kV, grounded-wye, low-voltage
Taps: In the high-voltage winding, 2½ and 5% above and below 230 kV
Load tap changer: In the low-voltage winding, sixteen ⅝% taps above and sixteen ⅝% taps below rated voltage

Phase: 3
Frequency: 60 Hz
Capacity: 10,000 kVA
Type: 0A
Transformer connections: Wye—Delta-Wye

Powerhouse-Station Service
- Number of transformers: 4
- Volts: 12,500—480Y/277 (2 transformers)
- Volts: 13,800—480Y/277 (2 transformers)
- Phase: 3
- Frequency: 60 Hz
- Capacity: 2,500/3,300 kVA
- Type: AA/FA

Area Control Center
- Number of transformers: 2
- Volts: 13,800—480Y/277
- Phase: 3
- Frequency: 60 Hz
- Capacity: 1,000 kVA
- Type: AA/FA

Intake Structure
- One transformer: 300 kVA, 13,800—480Y/277 V, type OA, 3 phase, 60 Hz

Engine—Generator Set
- Capacity: 625 kVA
- Power factor: 80%
- Volts: 4,160Y/2,400, 3 phase, 60 Hz

Generators and Motor-Generators

Electrical characteristics for the generators did not involve special requirements for this installation; consequently, the manufacturer's standard values were selected allowing minimum costs. Horsepower rating as a motor for the motor-generator was established by pumping requirements. Maximum horsepower of the pump occurs at minimum head, a condition which will be experienced infrequently. The maximum motor rating was thus established at 173,000 hp, 100% power factor, and a temperature rise of 80 degrees Celsius. Under the normally lighter load operating conditions, the motor will operate at lower temperatures and have a capacity for operating to 95% power factor. Electrical characteristics of the motor-generator were therefore determined by the motor, leaving surplus capacity for the generator rating. Although normal operation is at 95% power factor, the power factor for the generating mode was specified at 85%. This required a larger exciter but not a more costly generator. The primary reason for this was the uncertainty of future requirements for var supply from Edward Hyatt Powerplant. A possibility existed that the Department would construct transmission lines to its nearest major pumping plant, a distance of approximately 150 miles. The rated voltages were selected by the manufacturer within specified limits of 12.0 to 13.8 kV for generator operation and 11.5 to 13.2 kV for motor operation (Figures 94 and 95).

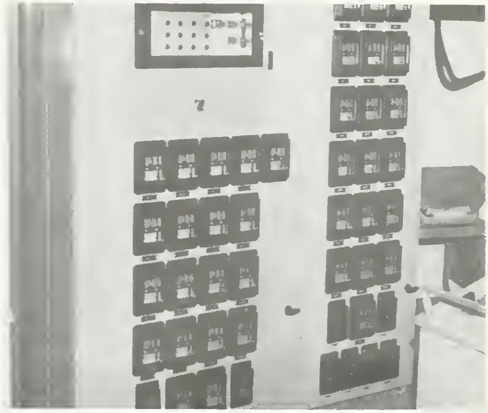

Figure 93. Emergency Control Relay Board for Thermalito Powerplant

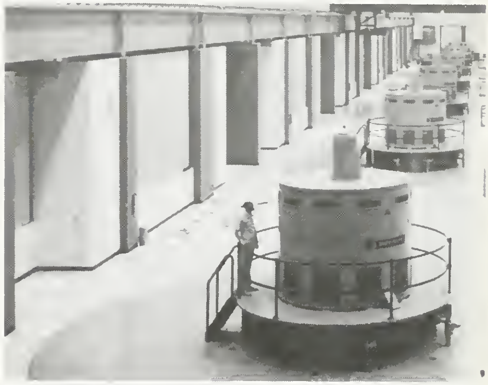

Figure 94. Motor-Generator Exciter

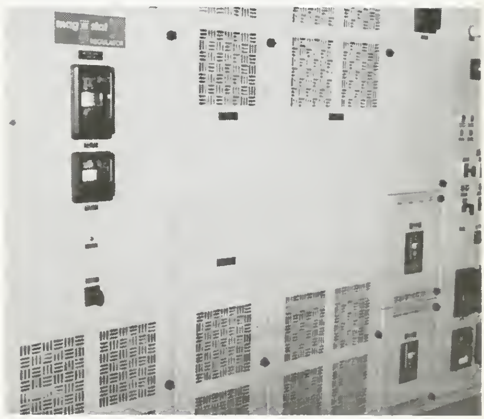

Figure 95. Motor-Generator Excitation and Voltage-Regulator Equipment

Limited clearance in the powerhouse made it necessary to limit shaft lengths on the generators and motor-generators. Shafts were specified in two lengths. One shaft section carries the rotor; the other is used for the exciter and thrust bearing. Two guide bearings, one above and one below the rotor, were specified for maximum mechanical stability. The thrust bearing is located above the rotor. This location provides better accessibility for dismantling. Limited available space below the generator floor essentially precluded locating the bearing below the rotor.

Damper windings were specified for the generators to provide protection against resonant circuits and high voltages in the event of a line to ground fault. On the motor-generators, amortisseur windings required for motor starting also serve as damper windings during generator operation.

Motor Starting Method

A motor is started by a generator unit operating at reduced frequency. Water is depressed below the pump impeller. The generator unit is started without excitation by opening the turbine wicket gates and, when it has reached 50% of rated speed, the motor is electrically connected to the generator by closing the 230-kV transfer bus breaker and 230-kV switch in the switchyard. At this point, the generator field breaker is closed. The motor starts and accelerates as an induction machine. When the motor reaches approximately 95% of the generator 30-Hz speed, the motor field breaker is closed to pull the motor into synchronism with the generator. Both units are accelerated at a controlled rate as the governor slowly opens the turbine wicket gates of the generating unit. When the motor reaches rated speed and proper synchronizing conditions, its 230-kV main bus breaker is closed, paralleling it with the utility system. The generator is then brought to no-load and disconnected from the motor. Air is then purged from the pump casing and the wicket gates are opened to commence pumping. The generator unit may then be shut down or slowed to 30-Hz speed for starting another motor.

Power Transformers

Transformers are dual-rated at 55 degree Celsius and 65 degree Celsius temperature rise. The kVA capacity was specified so the 65 degree Celsius, 112%, transformer rating would be equal to the specified 80 degree Celsius, 115%, rating of the generators. In practice, the units are operated for peaking power generation, frequently at or near 115% rated capacity.

In less than four years after beginning operations, three power transformers failed in service. The transformers are 3-phase core-type. Inspection of each core and coil assembly revealed that mechanical failure of the low-voltage windings led to turn-to-turn faults resulting in a single-phase fault to the core. All transformers have been repaired.

Power Transformer Location

Location of power transformers became the object of a special study after the decision had been made to locate the powerhouse underground. Three possible locations were selected for detailed examination and consisted of: (1) underground in the powerhouse, (2) underground in a separate vault, and (3) aboveground in the switchyard.

The underground location in the powerhouse was selected primarily because the low-voltage leads were as short as could be reasonably made and economics favored this location. Since the power requirements for each generator made the use of isolated-phase bus necessary, reduction in length was important for savings in capital costs and losses. Transformers could be located between generators by taking advantage of the space formed by the curvature of the generators. The width of the plant could be kept to a minimum, thus avoiding excavation and rock support problems associated with greater widths. The length of the plant was increased; however, width was considered to be more critical. By locating the transformers at a lower elevation in the powerhouse, they could be installed or removed (untanked) without an increase in crane height above that required for the generators and turbines. Installation in individual concrete vaults allowed use of CO_2 for fire protection.

Transformer location in an excavated vault adjacent to the powerhouse was also considered. This layout would require an excavation as long as the powerhouse and of a width to allow movement of one transformer past others remaining in operation. Interconnecting tunnels to the powerhouse for low-voltage bus, control cables, and access would be required. The powerhouse access tunnel required for the generators and turbines would be complicated by the need to move transformers to another vault. Untanking would be done outside of the machine hall. Estimates of the cost of excavation and low-voltage bus for the two underground locations favored the selected location inside the powerhouse.

Outside location of transformers had the advantage of available space and relative ease of access for maintenance and moving; however, these factors did not have sufficient economic advantage. The distance from the powerhouse to the switchyard area precluded this location due to the cost of low-voltage bus as compared to high-voltage insulated cable. Also, a tunnel for low-voltage bus needed to be much larger than that required for the 230-kV cable.

High-Voltage System

230-kV Switchyard. The switchyard at Edward Hyatt Powerplant includes bays for three transmission lines, three generator lines, and three lines to the motor-generators (Figures 96 and 97). The bus layout is essentially a main-and-transfer type except it is modified to include two breakers in each motor-generator bay. No transfer breaker is necessary since the double-breaker bays serve the same purpose. The transfer bus is also used as a starting bus whenever a motor is started. The main bus contains two sectionalizing disconnect switches which divide the yard into three sections, each containing one transmission, one generator, and one motor-generator bay. Sectionalizing switches are normally in the open position and were installed to provide flexibility and reliability of operation, mainly for the transmission circuits. The 230-13.8-kV station service transformer is connected to the main bus by means of a disconnect switch.

The switchyard was designed with a low profile and A-frame line towers. Rigid-pipe bus is used for the main, transfer, and cross-bus connections. The region is of relatively low seismicity; consequently, the low-profile rigid-bus design was selected.

Flexibility of operation is the most important factor in selecting bus arrangements for switchyards of this size. Additional complications were caused by the additional requirements of starting a motor by connections to a generator through the switchyard. Three arrangements were examined, namely: main-and-transfer, double-breaker, and breaker-and-a-half. While the breaker-and-a-half arrangement was attractive because of switching flexibility and reliability of operation, it was abandoned because of its greater space requirement for depth. Space available between the river and hillside was inadequate without extensive excavation, resulting in relatively high costs. The other two layouts essentially were combined to produce the selected yard containing three bays with double breakers and six bays with single breakers. Adequate operating flexibility was achieved using this arrangement.

230-kV Cable. Connections between the switchyard and the high-voltage bushings of the power transformers were made with cable. A high-pressure, oil-pipe-type, cable system was selected with cables rated 230 kV, 1,050 BIL, 145 MVA, 100% load factor, and with 500-MCM copper area. Ambient temperature is maintained below 85 degrees Fahrenheit in the cable tunnel. Cables are sheathless-type with oil-impregnated paper insulation and compact round-copper conductors. The three cables (one per phase) were installed in an 8-inch-diameter steel pipe. Oil pressure in the pipe is maintained at 200 psi (Figure 98).

Six pipe-type cables were installed in a tunnel which extended from the switchyard into the powerhouse for a distance of approximately 2,300 feet. The pipe is anchored at both ends and two intermediate points. Anchoring at both ends prevents motion of the pipe which could result in stress on the potheads. Intermediate anchor points also prevent downhill creep of the pipe caused by temperature variations. Detailed studies were conducted to determine the optimum anchor positions.

Trifurcator joints were installed at each end of the

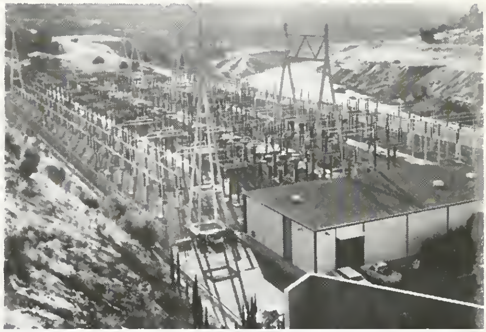

Figure 96. 230-kV Switchyard

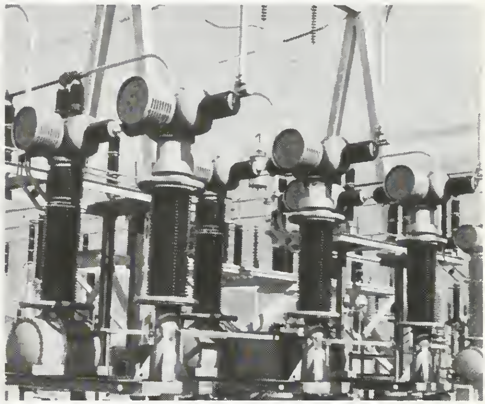

Figure 97. 230-kV Air-Blast Circuit Breaker

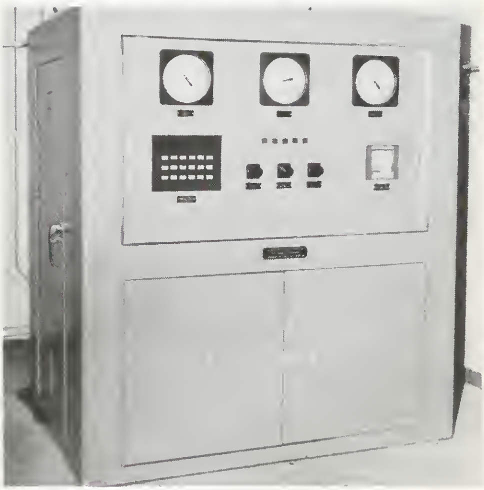

Figure 98. Pump Control Cabinet for 230-kV Oil Pipe Cable

pipe to convert the 8-inch pipe with three conductors to a 4-inch tubing with a single conductor. The joints also served for splicing the main cable to the pothead terminal cable stub.

Three lightning arresters were installed at the terminal end of the cable in the switchyard at the potheads (Figures 99 and 100). In addition, three arresters are located at the other end of the cable in the transformer vaults. Studies conducted on surge behavior in the cables indicated that the arresters at the transformers were not necessary. Switchyard arresters and attenuation in the cables would prevent destructive voltage surges at the transformers. A decision was made to install arresters at the transformers as additional precaution since the cost was considered to be small as compared to possible damage if protective arresters in the switchyard failed to perform.

During design of the cable installation, careful attention was given to oil pressures in the pipe. Differences in elevation at the two ends, in addition to the minimum required pressure in the pipe, determined the pressure at the lower pothead. The resulting value appeared too close to pothead pressure-withstand values. The pipe could have been sectionalized to reduce resultant pressures; however, manufacturers of the potheads gave assurance that adequate capabilities of potheads could be established.

Transmission Lines. Although not a part of Edward Hyatt Powerplant, the Oroville-Thermalito transmission lines are described here for continuity. The lines transport the energy generated at Edward Hyatt and Thermalito Powerplants to the Table Mountain Substation of the Pacific Gas and Electric Company when the plants are in the generating mode and deliver energy to the plants from the Substation when the plants are in the pumping mode.

Two double-circuit, 230-kV, steel-tower, transmission lines run from the switchyard at Hyatt to the Table Mountain Substation, a distance of 9 miles. One circuit has not been strung. The generating capacity of Edward Hyatt Powerplant is therefore divided among three circuits. In the case of an outage of any one circuit, full output of the plant can be transmitted over the remaining two. Two circuits from Thermalito Powerplant are tapped into two of the three circuits from Hyatt Powerplant.

Station Service System

The normal station service power source is from the 230-kV main bus through a step-down transformer and 13.8-kV distribution switchgear located in the switchyard. Two independent feeder circuits are routed to the powerhouse, control building, and intake structure; one circuit supplies the spillway. Back-up power for the powerhouse is received through 13.8-kV feeders connected to two generators (Figures 101 and 102). Two main, 480-volt, distribution boards in the powerhouse receive power either from the normal or

Figure 99. Indoor 230-kV Transformer Termination

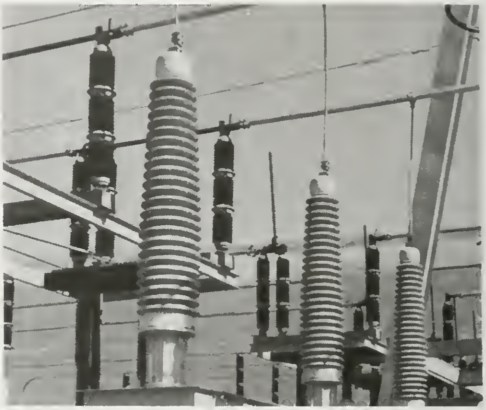

Figure 100. 230-kV Oil Pipe Cable Termination

Figure 101. 2,500-kVA Station Service Transformer

back-up supply (Figure 103). Located adjacent to the loads throughout the plant are 480-volt motor-control centers and secondary distribution boards. Each of these centers receives power from either of the main, 480-volt, distribution boards. An engine-generator set provides power to essential loads if other sources fail. Nonessential station service loads will be automatically dropped to stay within the capacity of the set.

The station service transformer in the switchyard has a grounded-wye connection on both the 230-kV and 13.8-kV windings (Figure 104). It has a delta-connected tertiary for suppression of harmonics and for neutral stabilization. The wye connection was selected to give a grounded 13.8-kV system. The same phase relation and position will occur in the back-up power supply.

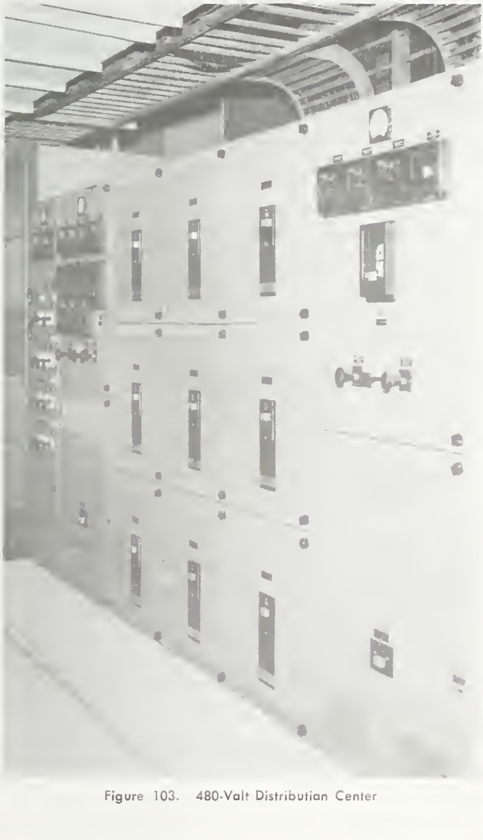

Figure 103. 480-Volt Distribution Center

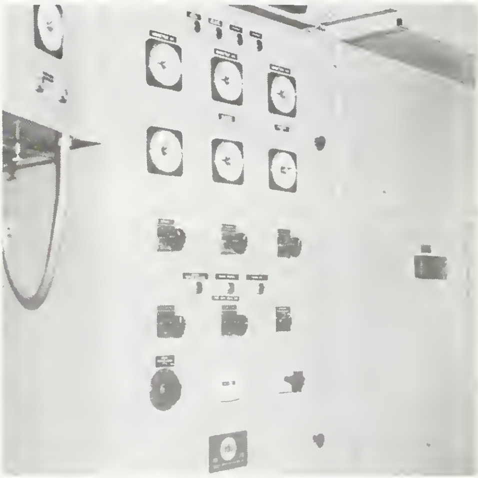

Figure 102. 13.8-kV Station Service Distribution Board

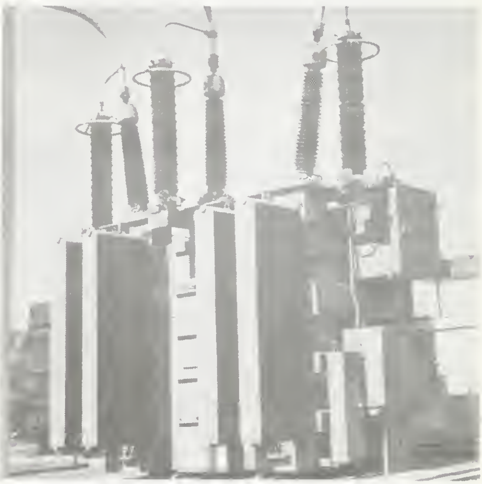

Figure 104. 10-MVA Station Service Transformer

Construction

Contract Administration

General information about the major contracts for the construction of the Edward Hyatt Powerplant is shown in Table 2. The principal construction contracts were the Oroville Powerplant, Specification No. 63-06; Completion of Oroville Powerplant, Specification No. 66-32; and Completion of Penstock Intake-Left Abutment, Specification No. 65-52. In addition, other large contracts which involved many complex problems and major costs were: Turbines and Pump-Turbines, Specification No. 63-05; 114-Inch Spherical Valves, Specification No. 64-13; Generators and Motor-Generators, Specification No. 64-16; Trashracks Supports and Control Shutters, Specification No. 65-11; and the Completion of Penstock Intake, Specification No. 65-52.

Powerhouse and Tunnel Excavation

Underground excavation for Edward Hyatt Powerplant (Figure 105) consisted of removal and disposal of excavated rock from the following: powerhouse access tunnel, powerhouse, high-voltage-cable tunnel, penstock tunnels and shafts, draft-tube tunnels, river outlet access tunnel, and emergency exit tunnel.

All underground excavation was done by first drilling and blasting the rock. A typical cycle of events was: (1) drill, (2) load, (3) blast, (4) muck, and (5) rock bolt (or support). In general, the tunnels were excavated full face using a jumbo, on which varying numbers of drills were mounted. The powerhouse above elevation 276 feet was excavated full face with three headings. Below elevation 276 feet, a quarry-type method was used to drill the blast holes.

Figure 105. Edward Hyatt Underground Powerplant

Extensive use of rock bolts was made to reinforce the rock and minimize the use of conventional types of support. The permanent support system in the powerhouse above elevation 217 feet was rock rein-

TABLE 2. **Major Contracts—Edward Hyatt Powerplant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Turbines and pump-turbines	63-05	$7,238,791	$7,333,758	$277,346	6/17/63	7/ 8/69	Allis-Chalmers Mfg. Co.
Oroville Powerplant structure	63-06	18,366,780	25,570,791*	8,630,021	6/24/63	4/ 3/67	McNamara Corp. & G. A. Fuller
114-inch spherical valves	64-13	2,259,760	2,591,840	131,375	3/30/64	2/11/69	Baldwin-Lima-Hamilton
Generator and motor-generator	64-16	6,427,899	6,683,288	468,688	7/ 3/64	2/21/69	Westinghouse Electric Corp.
Powerhouse cranes	64-19	299,950	308,489	--	6/26/64	11/16/67	Star Iron & Steel Co.
Generator switchgear	65-10	347,754	404,044	--	5/ 5/65	2/21/69	Westinghouse Electric Corp.
Trashracks, supports, and control shutters	65-11	1,961,870	2,075,766	--	4/30/65	7/26/67	Michel & Pfeffer Iron Works Inc.
Governors	65-14	415,294	431,221		5/21/65	6/19/69	Baldwin-Lima-Hamilton
Control switchboards	65-25	307,334	385,307	--	8/ 4/65	3/28/68	Westinghouse Electric Corp.
Power transformers, substation transformers, and lightning arresters	65-31	1,434,990	1,510,209	--	8/25/65	8/ 8/69	Maloney Electric Co.
230-kV circuit breakers	65-38	924,790	1,001,793	--	12/29/65	2/ 3/69	General Electric Co.
Completion of penstock intake, left abutment	65-52	4,429,816	4,732,887	317,545	1/25/66	3/28/68	Yuba Consolidated Industries, Inc.
230-kV cable pot heads	66-29	202,450	212,062	1,188	6/29/66	2/21/69	G & W Electric Specialty Co.
Completion contract	66-32	10,584,565	11,573,478	634,518	8/31/66	6/ 4/69	Wismer & Becker Contracting Engineers
Station service switchgear	66-35	491,200	525,390	13,970	9/28/66	6/ 2/69	Westinghouse Electric Corp.
Station batteries and associated equipment	66-36	69,491	73,983	1,490	9/27/66	7/26/68	Electric Storage Battery Co.

* In litigation—not final.

forcement in the form of grouted rock bolts. Elsewhere in the underground excavations, ungrouted rock bolts were used for temporary support and rock reinforcement prior to placing reinforced concrete for permanent support. Particular effort was made to install the rock bolts as close to the working face and as quickly as possible after blasting. Liberal use of chain-link fabric was made in the larger excavations in conjunction with the rock bolts to contain rock spall.

Rock bolting in the tunnels was done from a jumbo, using jackleg and stoper drills. Where access and equipment were available and convenient, jumbo liner drills also were used to drill rock-bolt holes.

Access Tunnel. Excavation to develop the portal face began in September 1963. A series of horizontal holes were drilled about 2 feet above the proposed arch, and 2-inch-square reinforcing bars, 20 feet long, were installed and grouted. An umbrella consisting of 5 steel sets was erected, lagged, and backfilled at the portal before commencement of tunnel excavation. This umbrella was later incorporated into the permanent portal design. Initially, the contractor advanced the heading by carrying a pilot drift in the crown several feet ahead of the face, then excavating the perimeter of the face, installing a steel set, and finally removing the center. However, after advancing approximately 20 feet, the contractor attempted to advance by 4-foot full-face rounds. During the mucking of the second such round, the tunnel back caved in to daylight (Figure 106).

Two rows of steel piling were driven, jump sets were installed between each set previously installed, reinforced-concrete buttress walls were constructed at the portal, and the steel umbrella was extended 15 feet. The contractor then advanced the heading by the use of wall plate drifts and steel sets on 2-foot centers. After advancing approximately 20 feet, the contractor changed his procedure to full-face rounds and steel sets at 4-foot centers.

At Station 12+88, the contractor was directed to cease using steel sets and use 10-foot ungrouted rock bolts on 4-foot centers in the arch and upper walls of the tunnel. Initially, the bolts were installed at 400 foot-pounds torque. This was soon reduced to 350 foot-pounds as it was determined the latter value induced into the bolt the designed tension of 20,000 pounds. The excavation advanced steadily with no particular support problems. However, the miners, most of whom had never worked under rock bolts, became increasingly concerned. At Station 11+64, they walked out claiming unsafe support and demanding direct rock support be employed. The walkout was resolved by installing steel sets through the rock-bolted section (Figures 107 and 108).

Powerhouse. To reduce damage to the rock walls and arch of the powerhouse, special effort was required by the specifications to obtain smooth walls in the excavation. The contractor was required to develop controlled blasting techniques which would

Figure 106. Access Tunnel Cove-in

Figure 107. Access Tunnel Showing "Steel Sets" Installed

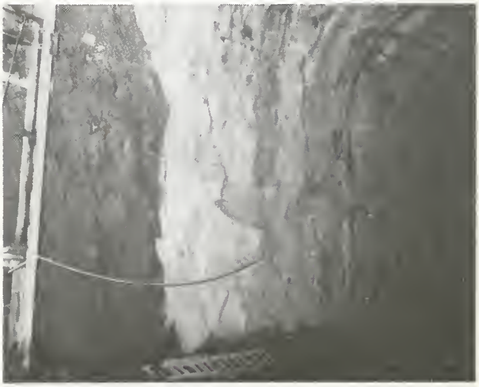

Figure 108. Rock-Bolted Section of Access Tunnel

leave 50% of the drill traces visible on the finished surfaces and would confine the finished surfaces generally within a 12-inch zone back of the minimum excavation line. The excavation of the arch and walls above elevation 213 feet was generally accomplished in conformance with these requirements. Below elevation 213 feet, these requirements were not imposed except in the downward extensions of the powerhouse walls.

Rock bolts in the powerhouse arch were 1-inch-diameter, 20-foot-long, groutable type installed on 4-foot centers (Figure 109). Small quantities of additional bolts were installed as local conditions required (Figure 110). To meet the 5-foot three-hour requirements, the contractor was limited, for the most part, to pulling 4-foot rounds. Holes were predrilled at the face and the bolts installed after the next muck cycle, when another row of holes was drilled.

Rock bolts in the powerhouse walls were installed and grounted on 6-foot centers as the excavation progressed. Rock bolts were grouted at least seven days prior to adjacent blasting. As the contractor started excavation of a given lift, there was at least a seven-day lag between rock-bolt grouting and blasting.

Chain-link fabric surface covering was installed on the vertical walls from the arch down to 10 to 15 feet above invert grades.

Some of the turbine pits were excavated by cutting a shaft in the center of the pit into the draft-tube access tunnel below, then shrinking into the center hole.

High-Voltage-Cable Tunnel. After the access tunnel heading reached the powerhouse, excavation for the high-voltage-cable tunnel was started. Blast holes were drilled with four liners attached to a drill jumbo. Six-foot rounds were drilled and blasted. Rock bolts, 10 feet long, were installed on 4-foot centers in the arch and upper walls. Holes were drilled with jacklegs and bolts installed from the muck pile.

Penstocks. The high-voltage-cable tunnel was extended into the powerhouse in the form of the penstock access tunnel. The tunnel was essentially the same size as the high-voltage-cable tunnel, ramped down to invert elevation 198± feet at Unit No. 6 and extended to Unit No. 1. The heading was advanced as rapidly as possible. No support other than minimal spot usage for rock bolts was followed.

Multiple headings were used in the excavation of the penstock branches (Figure 111). Ten-foot rock bolts were installed on 4-foot centers in the arch above the springline. Excavation methods and equipment used were the same as for the high-voltage-cable tunnel, except the 22-foot sections of the penstocks were excavated with a top heading and bottom bench to the 55-degree incline. The bench (about 8 feet) was later removed by advancing a heading into the bench.

The incline and shaft sections of the penstocks were excavated by first driving a pilot raise approximately 7 feet in diameter to about 50 to 60 feet below surface. Following the excavation of the penstock transition sections (included in the bid item for structural excavation), the excavation of the penstock shaft was com-

Figure 109. Powerhouse Arch—Grouting Rock Bolts

Figure 110. Powerhouse Arch

Figure 111. Transition of Penstock Branch No. 6 Showing Satisfactory Results of Controlled Blasting

pleted as a reaming activity shrinking into the raise. Muck was removed from below through the powerhouse. The raises were driven unsupported, using jacklegs to drill from a raise climber. The shafts were sunk by drilling blast holes with jacklegs and blasting into the pilot raise. Access to the face was provided with a man-trip riding on tracks and operated through a head-frame at the collar of the shaft. Occasionally the muck would hang up and plug the pilot raise. On one occasion, it took three weeks to break the plug loose. Ten-foot-long rock bolts were installed on 4-foot centers for the full diameter of the tunnels, except for the portions of each penstock at the upper elbow where direct steel support was used.

Draft Tubes. To expedite excavation of the draft-tube tunnels, the contractor excavated an access tunnel by enlarging the dewatering gallery, with an invert grade at elevation 160 feet.

The draft-tube access tunnel was started by branching from the penstock access tunnel near Unit No. 6 down and into the service bay, with a switchback at the powerhouse end wall, and then down to the dewatering gallery and through to Unit No. 1. The draft-tube access tunnel was essentially unsupported except for the use of direct steel support in the area where the tunnel passed under the penstock access tunnel and spot usage of rock bolts in other locations (Figure 112).

Muck was pulled from draft tubes Nos. 1 through 4 with a slusher into the access tunnel, where it was loaded and removed. The invert grade of draft tubes Nos. 5 and 6 was flat enough to allow use of a loader at the heading. The top headings in draft tubes Nos. 1 through 4 were drilled with jacklegs from a leveled muck pile. Rock bolts also were installed off the muck pile. Headings in draft tubes Nos. 5 and 6 were drilled, and rock bolts were installed using a drill jumbo. Rock bolts were installed on 4-foot centers above the springline throughout the draft tubes. Permanent concrete was placed in the transition sections of the draft tubes

Figure 112. Draft-Tube Access Tunnel Looking Toward Machine Hall

prior to excavation of the corresponding turbine pits.

Emergency Exit Tunnel. Blast holes and rock-bolt holes for the emergency exit tunnel were drilled with jacklegs. Six-foot-deep rounds were pulled. A mucking machine and a 2-cubic-yard shuttle car were used to load and transport the tunnel muck. Eight-foot rock bolts were installed on 4-foot centers in the arch while steel sets were used in the initial 25 feet of the portal.

River Outlet Access Tunnel. Excavation was started from the powerhouse end wall. Muck was dropped into the powerhouse and removed with the powerhouse excavation. Drilling was done with jacklegs from a platform. Eight-foot rock bolts on 4-foot centers were installed in the arch.

Structural Excavation

This work included excavation for building foundations, switchyard structures, high-voltage and control-cable tunnel, and the portal wall; also structures for the conduit, drainage, sewage and water systems, and for the gas purge line.

Excavation began for the high-voltage and control-cable tunnel in November 1966. Presplit holes were drilled and shot, followed by pattern hole blasting and removal of material. Material was removed and hauled to the designated waste areas. Removal of the final few inches of material was done with a small backhoe, pneumatic tools, and hand-tool trimming. Excavation for the cut- and cover-tunnel, control building, and emergency generator vault was done in the aforementioned manner. Following excavation of the curve portion of the tunnel section, work began on the control building. Essentially, all structure excavation was completed by January 1968.

Left and Right Abutment Intake Excavation

Construction of the left and right abutment intakes (and access roads) required over one million cubic yards of excavation, of which 864,000 cubic yards were open-cut excavation and 122,000 cubic yards were structural excavation. A total of 48,000 cubic yards of concrete was placed in the two structures. In the left intake foundation, 936 grouted rock bolts were placed. The left and right abutment structures were backfilled with approximately 70,000 cubic yards of shot rock.

A different approach was used to drill and blast on each abutment. The approximate original ground line and the finished excavation on the left abutment were on a 1.9:1 slope (Figure 113). Bulldozers stripped all soil from the excavation and pushed it to where either scrapers or a shovel and dump trucks removed it from the intake site. The resulting rock surface was quite steep and irregular with knobs and vertical faces. It was necessary, in order to permit drilling, to raise and lower each drill with air tuggers. On the irregular surface, the depth of drilling varied from 4 to 40 feet to the plane between the contract limits of structural and open-cut excavation. After the open-cut excava-

Figure 113. Left Abutment Intake Excavation

tion had been removed, the drills were again lowered down the slope to drill the structural excavation portion. Drilling was generally done on a 7-foot by 7-foot grid pattern.

During excavation of the left intake, all waste material was hauled from one of the four levels of haul roads constructed to the waste area at elevation 750 feet. These haul roads entered the intake excavation at elevations 921, 750, 650, and 615 feet.

The right abutment intake excavation was on a 3.2:1 slope, considerably flatter than the left abutment excavation (Figure 114). Open-cut excavation was performed on a series of benches at elevations 750, 720, and 684 feet. Rock was drilled and shot in approximately rectangular areas on the benches with the shovel following and excavating material as soon as it was shot. This method required holes approximately 30 and 36 feet deep. Holes were usually spaced on a 7-foot by 7-foot pattern.

The contractor used from one to four drills during drilling operations on each abutment. The 3½-inch bits used in the drilling were usually good for 50 feet of drilling in the slightly weathered rock on the left abutment but had to be sharpened after as little as 14 feet of drilling in hard fresh rock on the right abutment.

After completion of rough excavation of right and left abutment intakes, drillers returned and drilled and blasted shear keys in the intake channel foundations and also the trench for the 2-foot-diameter air vent pipe which runs up the center of each intake channel. Blasts for these areas loosened the foundation rock along the sides of the trenches and lower face of the keys, thereby contributing to overbreak in these areas. In addition, certain areas of the channels in the left intake contained unsuitable material at the finished grade. These areas were further excavated by a backhoe to depths of up to 7 feet.

This backhoe also was used to remove muck left by the bulldozers. Muck was placed below the tractor on the slope for a bench from which to work. Laborers, with air and water hoses, cleaned the rock surface immediately behind the backhoe so it could lift out the accumulated material. A bulldozer was used to move the bulk of the material downslope. When the cleanup operation reached the foundation keys, a heavy backhoe was used in the final stages of cleanup.

Drilling in the right abutment penstock shafts was done by five to six miners with jackhammers drilling 6-foot rounds which could be drilled out in approximately 12 hours. Mucking was done by loading 1½-cubic-yard muck buckets which were hoisted by a crane on the permanent bench at elevation 684 feet.

Excavation for the left intake structure included excavation of the penstock shaft transitions which ran from elevation 573 down to 535 feet. From the powerhouse below, miners had tunneled 7-foot-diameter raises up penstocks Nos. 1 and 2 to within 65 feet of the surface. After drilling into these raises fom the surface, small charges were lowered to within 5 feet of the top of the raise, and successive blasts were made downward, with muck being removed through the powerhouse until the full 7-foot-diameter raise was opened to the surface (Figure 115). Both penstock transitions Nos. 1 and 2 were rock bolted around their periphery and chain-link mesh was installed for protection from loose rocks.

Backfilling of Left and Right Abutment Intake Structures

Backfilling of the redesigned left and right abutment intake structures required protection of workmen from rolling rocks. To accomplish this, the

Figure 114. Right Abutment Intake Excavation

contractor fabricated protection barriers from wide-flange beams and railroad rails. These barriers were installed outside of walls in the lower end of the left intake.

Hard rock from 4 inches to 3 feet in size was needed for backfill, so fresh rock blasted from the right abutment intake excavation was stockpiled on the right abutment waste area during excavation. In addition, a small amount of rock was available from core trench excavation that had been stockpiled on the left abutment by the Oroville Dam contractor.

The right abutment intake structure was backfilled by dump trucks which hauled the backfill to the intake channels at elevation 684 feet. From this level, it was end-dumped and bulldozed to grade against the outside of and between the intake walls.

Rock was transported from the right abutment stockpile to the left abutment in end-dump trucks for dumping around storage bays and along the left side of Intake No. 1 and right side of Intake No. 2 (Figure 116). It was also hauled in 4-cubic-yard rock skips with three skips per truck-trailer for placing between the two intake channels with a 10-ton-capacity highline. The highline placed approximately 240 cubic yards per shift. As rock was dumped from buckets by the highline, a bulldozer graded the rock and kept a level bench to facilitate dumping.

After the right abutment stockpile was depleted, the loading operation was moved to the powerhouse muck pile, southeast of the switchyard. Later, all material was obtained from a stockpile in the left abutment waste area.

Dump trucks hauled rock to the backfill area adjacent to the channel walls immediately in front of the storage bay walls at elevation 905 feet. A bulldozer drifted and graded the material downslope to where the highline had been used to backfill. Three bulldozers pushed all subsequent material upslope from the bench at elevation 613 feet.

Foundation Grouting and Drainage

Oroville Powerplant was constructed with a grout envelope from 40 feet to 90 feet deep from the excavated rock surface. The rock to a depth of 40 feet was left ungrouted to provide a zone of free drainage. The grout envelope furnishes a relatively impermeable zone surrounding the Powerplant. The free-drainage zone precludes development of hydrostatic pressures in the foundation rock adjacent to the powerhouse structure (Figure 117).

In addition to grout holes being left open from 0 to 40 feet above elevation 217 feet, additional drain holes were drilled into the rock surrounding the powerhouse structure. To relieve hydrostatic pressures, drain holes were drilled in the invert of the draft tubes. Drain holes also were drilled in the walls and arch of the access tunnel to relieve pressure and provide means to control drainage water.

Figure 115. Pilot Shaft Open in Penstock Shaft No. 2—Left Abutment Intake

Figure 116. Backfilling Right Side of Intake No. 2—Left Abutment Intake

Figure 117. Grout Plant Comprised of Two Moyno Pumps and Two Tanks

Consolidation grouting to ensure or improve the structural integrity of the rock was done in selected areas of the penstocks. With redesign of the intake structure and foundation, and upon evaluation of surface and subsurface data obtained by drilling and water testing several holes, it was determined that blanket grouting of the intake structure foundation was not necessary, and the work was deleted.

Concrete Placement

Aboveground concrete placements on the Edward Hyatt Powerplant contract were made in the right and left abutment intake structures and in the switchyard drainage ditches (Figures 118 and 119). Drainage ditch placements consisted of pneumatically applied mortar. Underground placements consisted of backfill concrete for the exploratory tunnels; lining for the powerhouse access tunnel, draft tubes, penstocks, high-voltage-cable tunnel, emergency exit tunnel, and river outlet tunnel; mass concrete placements in the machine hall; and the pneumatic application of mortar to the arch of the machine hall.

The concrete consisted of Portland cement, pozzolan, sand, coarse aggregate, water, and various admixtures. Reinforcement consisted of reinforcing steel in most concrete placements, welded wire fabric for ditch lining, and chain-link fabric for guniting the machine hall arch.

All concrete, except that placed under the completion contract, was supplied by an automatic batch plant with three 2-cubic-yard tilting-drum mixers, capable of producing 110 cubic yards of concrete per hour. Concrete was transported from the batch plant to the placement sites using tilting-drum mixers as agitators only.

In general, 3-inch maximum size aggregate was used in all mass placements in the machine hall and right and left abutments and 1½-inch maximum size aggregate for all remaining placements throughout the project.

Figure 118. Placing Concrete in Left Abutment

Figure 119. Left Abutment Intake Concrete Placement

An aggregate of 1½ inches maximum size was used for all placements using a pumpcrete machine. For priming the slickline and for placements next to construction joints, a starter mix of ¾-inch maximum size aggregate plus additional cement was often used. For all concrete mixes, pozzolan was added at the rate of 70 pounds per cubic yard.

In general, mass placements were cured with wetted burlap. Where practical, the inverts often were flooded. The tunnel sections were cured with a sprinkler system. The ditch lining and gunite in the arch of the machine hall were cured by applying curing compound to the finished surface.

In the operating deck and storage bay areas, early placements were made using a crane and bucket with production rates varying from 9 cubic yards per hour for wall placements to 22 cubic yards per hour for open footing placements. Early placement of concrete by the highline averaged 24 cubic yards per hour. The rate of placement for mass concrete reached a high of 48 cubic yards per hour using a 4-cubic-yard bucket. Concrete placements were made during the night, thereby freeing the highline during the day for moving and setting forms and reinforcement steel. Concrete on the right abutment was placed with a crawler crane and a 3-cubic-yard bucket.

Metal forms were used for all placements requiring multiple uses, while wooden forms were constructed for placements requiring only limited usage. On the left abutment, subinvert concrete was placed in the channels with a step-type form to hold concrete on the 2:1 slope (Figure 120). The form was reusable, requiring only four hours to strip and reset for the next placement. On both the right and left abutments, invert channel placements were made with a slip-type form. The channel wall placements were placed in three lifts using 26-foot - 8-inch-long forms.

Figure 120. Form Used for Subinvert Concrete in Left Abutment Channel

A total of 590 cubic yards of concrete was placed within the various exploratory tunnel branches. Placements were made with a concrete pump.

In the powerhouse access tunnel, 12,812 cubic yards of concrete was placed under the bid item, and an additional 2,035 cubic yards were placed due to excessive overbreak. Concrete placements in the access tunnel were made in three sections: first, concrete curbs on both sides of the tunnel, then the concrete invert and, finally, the arch and walls of the tunnel. The access tunnel invert had to be placed so that it would not interfere with the initial contractor's work schedule and before the completion contractor needed to haul materials over it (Figure 121). This was accomplished by having all reinforcement steel made into mats and stacked along the walls of the Powerplant ready to place. Steel header-board forms were placed 1 foot away from the existing concrete curbs. The invert was then placed in one operation using a highway paving machine and standard finishing train. High early-strength concrete was obtained with a seven-sack mix.

The form for the walls and arch of the access tunnel was a metal collapsible type, mounted on rails laid on the finished invert. The form was designed to allow equipment to pass through it while in place. A pumpcrete machine placed all concrete within the metal form.

Total neat-line concrete placed in the machine hall amounted to 43,811 cubic yards. There was an additional 6,167 cubic yards of overbreak concrete placed below elevation 217 feet. The overbreak included 599 cubic yards of geological overbreak, 1,037 cubic yards of backfill for the draft-tube access tunnel, and 4,500 cubic yards of other overbreak.

Although concrete placement in the machine hall began before April 1966, transport of supplies and equipment necessary to commence full-scale concrete operations depended upon the contractor's completion of a work trestle. Following completion of the trestle, which was used as a platform for the operation of several cranes handling reinforcing bars, forms, and other supplies and equipment, a "beltcrete" setup was employed for the majority of the concrete placements. The beltcrete hopper was supplied by transit mix trucks driving onto, and discharging from, the trestle.

When concrete placements reached the point where forming was ready for the slab at elevation 252 feet, the work trestle was progressively removed. Placements of the floor slab were made by a concrete bucket suspended from a bridge crane. Access onto the floor at elevation 252 feet was critical, so a six-sack mix was used for high early strength for all floor slab placements.

A total of 6,380 cubic yards of concrete was placed in the draft tubes, of which 1,917 cubic yards were backfill concrete due to overexcavation. Concrete placements in the draft tubes began before excavation in the powerhouse was complete. Draft tube and draft-tube transition forms were brought in through the draft-tube access tunnel in sections and assembled in place.

A total of 20,300 cubic yards of concrete was placed within the penstocks, of which 6,900 cubic yards were backfill concrete due to overexcavation.

Lining the penstock branches was begun first. This involved pumping concrete from a pumpcrete machine located within the machine hall to the various penstock branch placements. Full-circle steel forms, approximately 28 feet long, were used along with form vibrators and stingers to consolidate the concrete.

Placing concrete in the raised sections of the penstocks began in February 1966. All placements were made from the foot of the left abutment intake structure at elevation 613 feet. A pumpcrete machine pumped concrete from the trucks to a holding hopper.

Figure 121. Access Tunnel Paving Operation

From the hopper, the concrete was gravity fed approximately 400 feet through a slickline to the placement site. The rate of flow in the slickline was controlled by a valve at the bottom end of the line.

The invert of the high-voltage-cable tunnel was placed first, followed by the arch and wall combined placements. Arch and wall placements were made using steel collapsible forms and a pumpcrete machine.

Concrete placements within the emergency exit tunnel and the river outlet tunnel totaled 2,100 cubic yards, of which 790 cubic yards were overbreak concrete.

The invert placements were completed first, followed by the arch and wall combined placements. Wooden forms were used throughout the river outlet tunnel, and metal forms were used throughout the emergency exit tunnel. All placements were made with a pumpcrete machine.

Pneumatically applied mortar was placed on the arch of the machine hall (Figure 122). Before guniting commenced, damaged sections of the wire mesh were replaced and the existing mesh pinned back to meet the contour of the rock surface using 2-foot-long, 1-inch-diameter, rock bolts. The rock surface was then washed down with an air-water jet gun. Oil was removed from the surface by sandblasting. Previously drilled holes were plugged to prevent filling with gunite.

Gunite was placed best when applied in several scratch coats before placing the final coat. Curing was with water between coats and a curing compound on the final coat. As the various scratch coats of gunite were applied, the gunite tended to separate from the rock. As the guniting proceeded, the amount of voids behind the gunite became considerable.

Apparently, the initial application of mortar stuck to the rock surface. A considerable amount of rebound off the closely spaced chain-link fabric also clung to the surface; and, as additional mortar was applied, the load became too heavy for the low cohesive strength of the rebound or deflected material, and the gunite separated. Repair to the machine hall arch gunite involved installing 5-foot groutable rock bolts, tensioned to 1,000 pounds, in a 4-foot pattern. To prevent pressure buildup behind the gunite lining, grouting pressures were limited to less than 10 psi. Testing was done by sounding and by drilling 3-inch core samples. After the repair work was completed, wet areas were drilled to relieve any static pressure or potential static pressure that might build up later. Approximately 2,450 bolts were installed in the arch, and 1,100 sacks of cement was used in grouting.

There were three main types of concrete placed on the completion contract: structural concrete, encasement concrete, and miscellaneous concrete. The major items under structural concrete included all buildings, the 114-inch spherical-valve platforms, the high-voltage-cable gallery and tunnel, the access tunnel portal, the control cable tunnel, and the emergency generator vault. Encasement concrete included concrete for encasing the upper portion of draft tubes, stay and discharge rings, scroll cases, and pit liners (Figure 123). Miscellaneous concrete included concrete for sidewalks; gutters; curbs; bases for light standards; switch operating platforms; and encasement of pipe, electrical conduit, and gas purge tube. The concrete was dry-batched at facilities in Oroville and transported to the job site in rear-dump trucks. The water and liquid admixtures were added at the job site and the concrete mixed in a dual-drum paver. This arrangement produced approximately 60 cubic yards per hour under optimum conditions.

Mechanical Installations

Oroville Powerplant (Specification No. 63-06). The principal mechanical work performed included furnishing and installing steel penstock liners, draft-tube gates, hoist and lifting beam, and embedded pip-

Figure 122. Guniting Arch of Powerhouse

Figure 123. Concrete Placement Around Scroll Case and Turbine Pit Liner of Unit No. 1

ing; installing draft-tube liners and piers, penstock transition sections, and two 200-ton cranes all furnished by the Department; and furnishing and installing miscellaneous mechanical equipment.

Six penstock branch liners, each 12 feet in diameter and approximately 100 feet long, were installed from the powerplant upstream side to convey water from the two concrete-lined penstock shafts to the turbines.

The penstock branch liners were fabricated from $1\frac{1}{2}$-inch steel in three sections per unit and weighed approximately 78,000 to 86,000 pounds each, depending on length of the section (Figure 124). They were loaded on steel skids, taken into the machine hall, and placed on rollers in the penstock branch tunnels. Welding was from inside the liners and, after a quarter of the circumference was welded, the sections were rotated on the rollers making another quarter of the circumference available to the welders. After welding, X-rays were taken and deficiencies corrected. When welding was completed, piezometer taps and salt-velocity electrode stations were installed, and the areas around the steel liners were backfilled with concrete.

After the liner section of each unit was concreted, the transition section was brought into the machine hall. These six low-carbon, alloy, heat-treated sections weighed approximately 55,000 pounds each and were cribbed into position for welding to the liners. The elevation and alignment of the flanged face of these transitions were held within $\frac{1}{32}$ of an inch to theoretical location after being welded to the liners. Welding of the transition section to the liners tended to cause distortion in the welded joint, forcing the flange out of alignment. It was discovered that by simultaneously welding two $\frac{1}{8}$ sections of circumference directly opposite each other, the distortion problem was eliminated and the necessary close tolerance was achieved. The welds were X-rayed and any deficiencies corrected.

The six draft-tube liners were fabricated from 1-inch steel in eight sections per unit. The eight sections were fitted and welded in the contractor's assembly yard into the maximum size that could be trucked into the machine hall. These were lowered into place from the work trestle by the construction bridge cranes. After the lower sections were aligned, piezometer taps installed, and piping connections made, the unit was embedded in concrete. The upper sections were then brought into the machine hall, aligned, and welded to the lower sections. During installation of the draft-tube gates and guides, it was discovered that the allowable tolerances of the head seals were exceeded by as much as $\frac{1}{8}$ of an inch. This was remedied by applying an epoxy formulation consisting of approximately 80% steel and 20% plastic. It was applied to the gate head seal areas and formed an extremely strong, durable, and rigid metallic mass. After the plastic steel was applied, it was ground to provide the required seal.

The draft-tube gate hoist, drainage and submersible pumps, oil storage tanks, elevator, and two 200-ton powerhouse cranes were installed without mechanical problems.

Penstock Intake, Left Abutment Oroville Powerplant (Specification No. 65-52). The principal mechanical work was the completion of the Edward Hyatt Powerplant left abutment penstock intake. The following principal features were included: two temporary bulkheads; two penstock intake gates, complete with tracks, seal seat frames, rails, carriages, and operators; one intake gate lifting beam; one penstock intake gate gantry hoist, complete with rails; one control shutter gantry crane, complete with rails; one control shutter lifting beam and rails for two intakes; and a control room. The work also included the assembling, installing, and testing of control shutters and trashracks (Figures 125 and 126).

Figure 124. Penstock Branch No. 6 With Steel Liner in Place

Figure 125. Rolling Scaffold Used for Forming and Concrete Embedment of Shutter Rail

Figure 126. Penstock Intake No. 1 Gate in Position on Its Carriage—Gate Roller Trains Are Installed

Figure 127. Intake No. 1 Valve and Body Halves Prior to Assembly

Completion of Oroville Powerplant (Specification No. 66-32). The principal features of mechanical work performed under Specification No. 66-32 included: piping, air compressor systems, heating, ventilating and air conditioning, fire protection system, domestic water and sewage disposal systems, emergency generator, oil-handling equipment, trashracks, hoists, and installation of the 114-inch spherical valves (Figure 127).

The fabrication and installation of the various features were, in general, routine. One notable change involved the 114-inch sperical valves. The 12 valve body halves and 6 plug castings were poured by January 26, 1966. About 34,444 square inches of stainless-steel overlay was applied to the six valves. Major defects were removed, outlined, located, and dimensioned on sketches sent to the Department for evaluation of repairs and approval of repairs and procedures. As the work progressed, and with the number of imperfections being noted, it became evident that the commercial-grade castings specified were not going to meet the needed requirements. To eliminate possibility of valve failure and extreme plant damage, it was decided to upgrade the castings to X-ray quality, and the manufacturing of the valves was successfully completed.

Furnishing and Installing Turbines and Pump-Turbines (Specification No. 63-05). The principal mechanical work was the manufacture and installation of three 161,000-horsepower hydraulic turbines and three 173,000-horsepower pump-turbines, each complete with spiral case, spiral case extension, draft-tube pier, draft-tube liner, and appurtenant parts.

Furnishing and Installing Generators and Motor-Generators (Specification No. 64-16). The principal mechanical work was the fabrication, installation, and field testing of three 123,157-kVA generators and three 115,000-kVA motor-generators.

The fabrication and installation of the equipment was routine, and no notable problems occurred other than those often encountered in the fabrication and installation of large turbines and generators (Figure 128).

Electrical Installations

The principal work was done under Specifications Nos. 63-06 and 66-32. The electrical work required the furnishing and installation of large quantities of wiring, lighting fixtures, conduit, cable trays, and miscellaneous electrical accessories. These installations were routine, and no notable problems occurred.

Oroville Powerplant (Specification No. 63-06). In general, the work consisted of furnishing and installing conduit and grounding systems which were embedded in the powerhouse and intake structure first-stage concrete; all embedded and exposed conduits, lighting fixtures, panel boards, and accessories for the powerhouse lighting system; all embedded inserts for supporting cable trays and power-cable conduit in the powerhouse, access tunnel, and cable tunnel; and the crane collector rail.

Completion of Oroville Powerplant (Specification No. 66-32). The principal features of the electrical work included conduit, lighting, and grounding systems; communication systems; 230-kV pipe-type cable systems; and switchyard facilities. It entailed all installations to complete the electrical system for the powerhouse, switchyard, control building, and appurtenant structures.

Figure 128. Lowering First Section of Stator on Soleplates in Generator Pit No. 1

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 129 through 173).

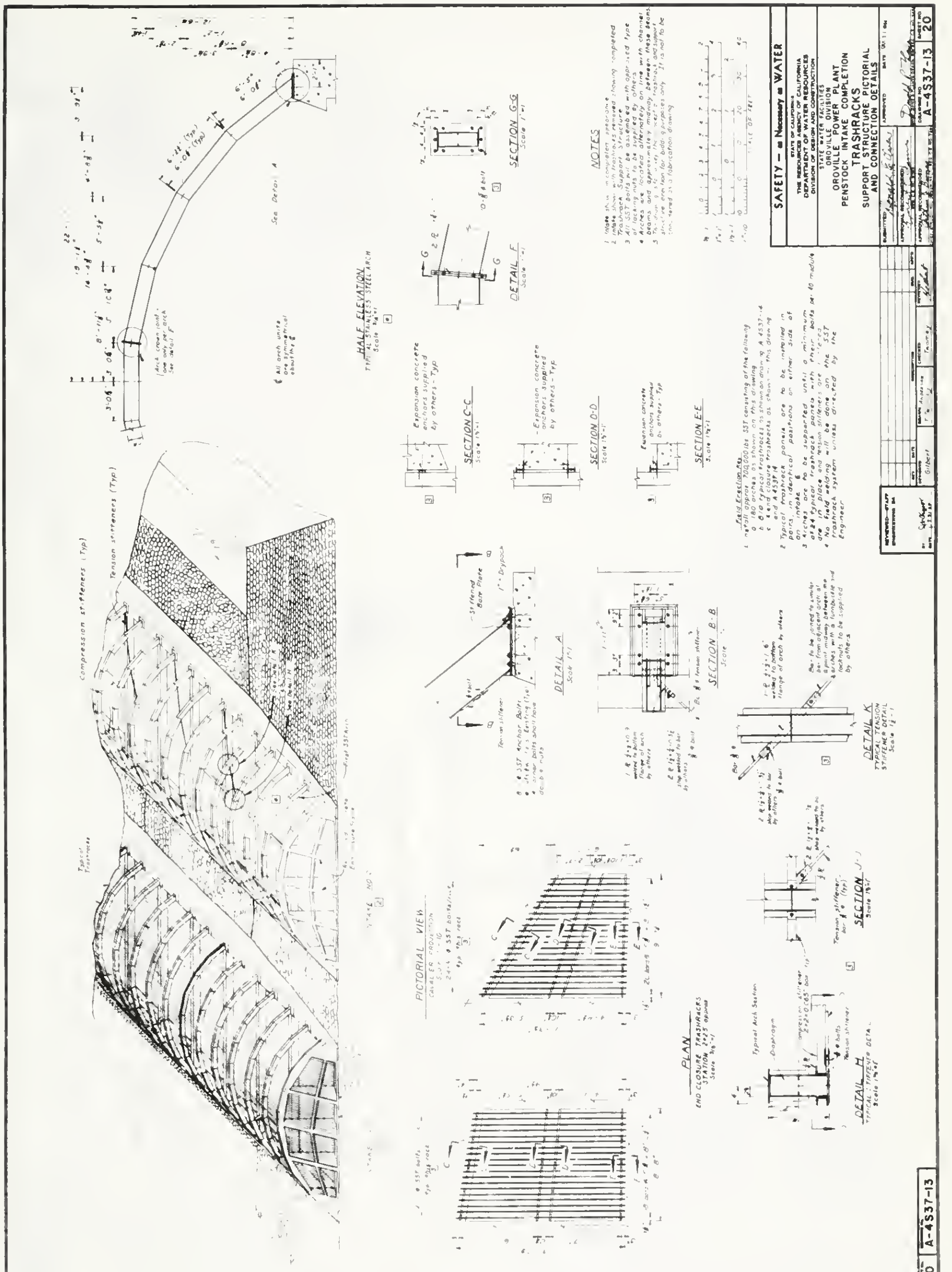

Figure 129. Trashracks

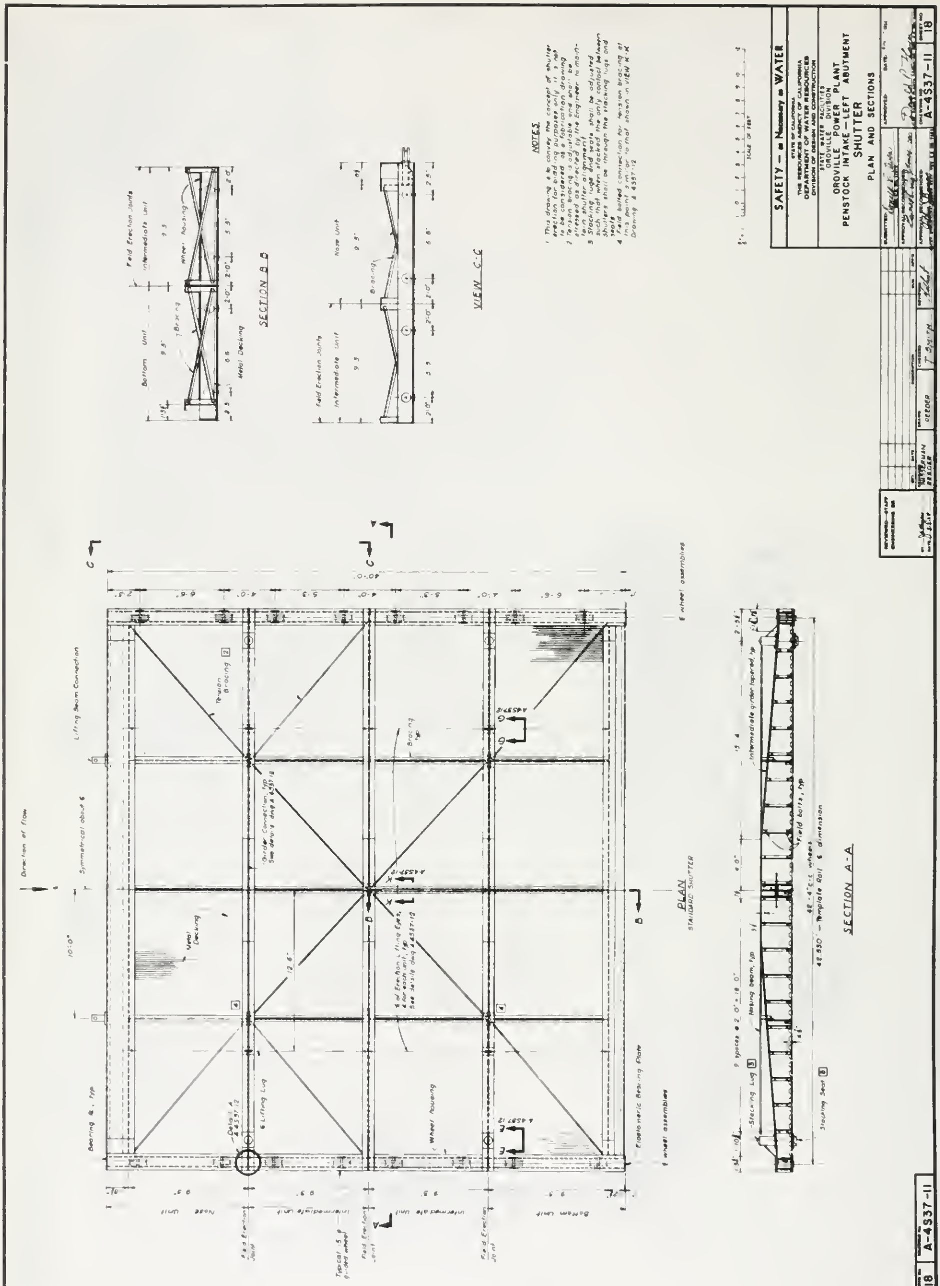

Figure 130. Penstock Intake—Shutter

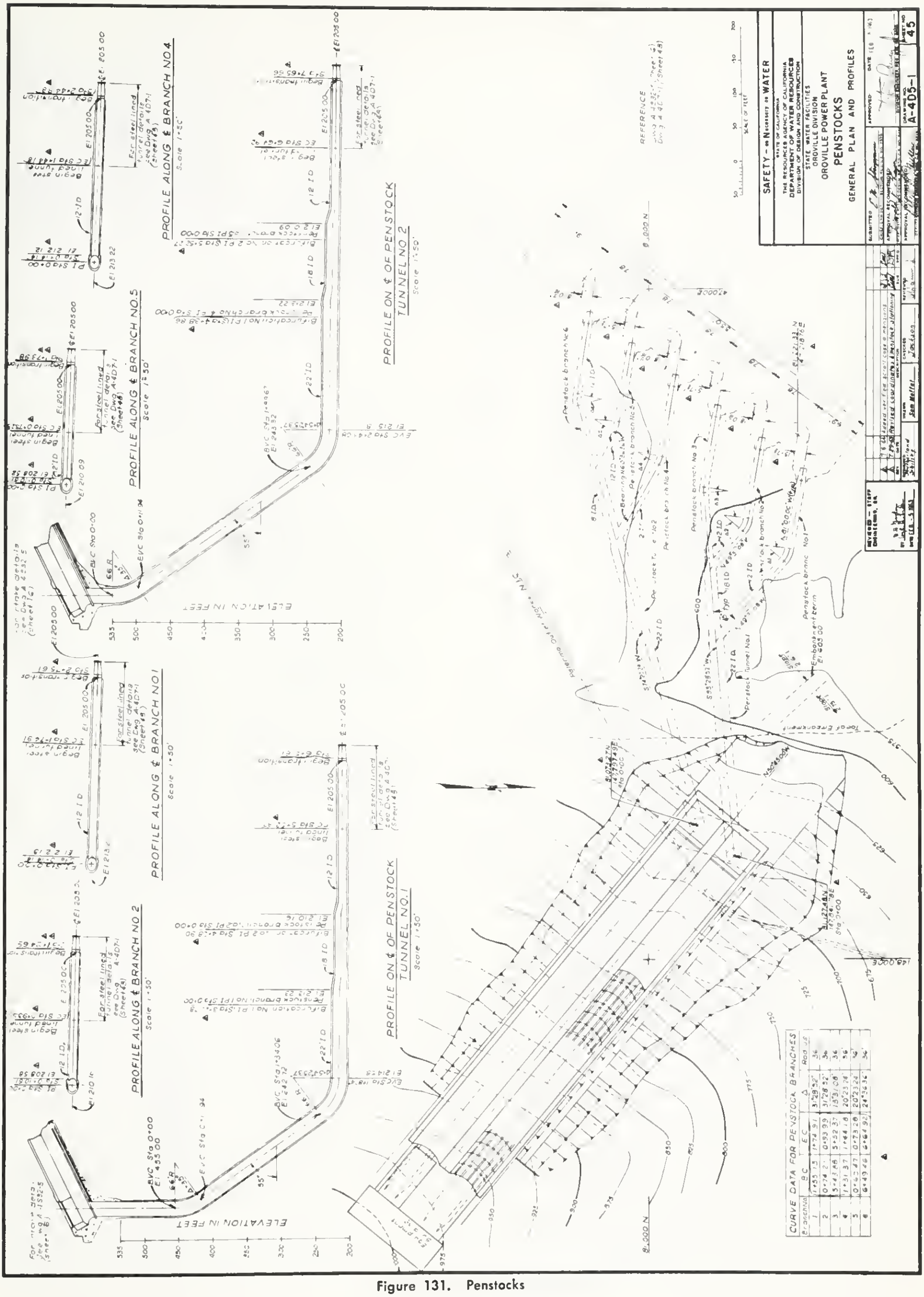

Figure 131. Penstocks

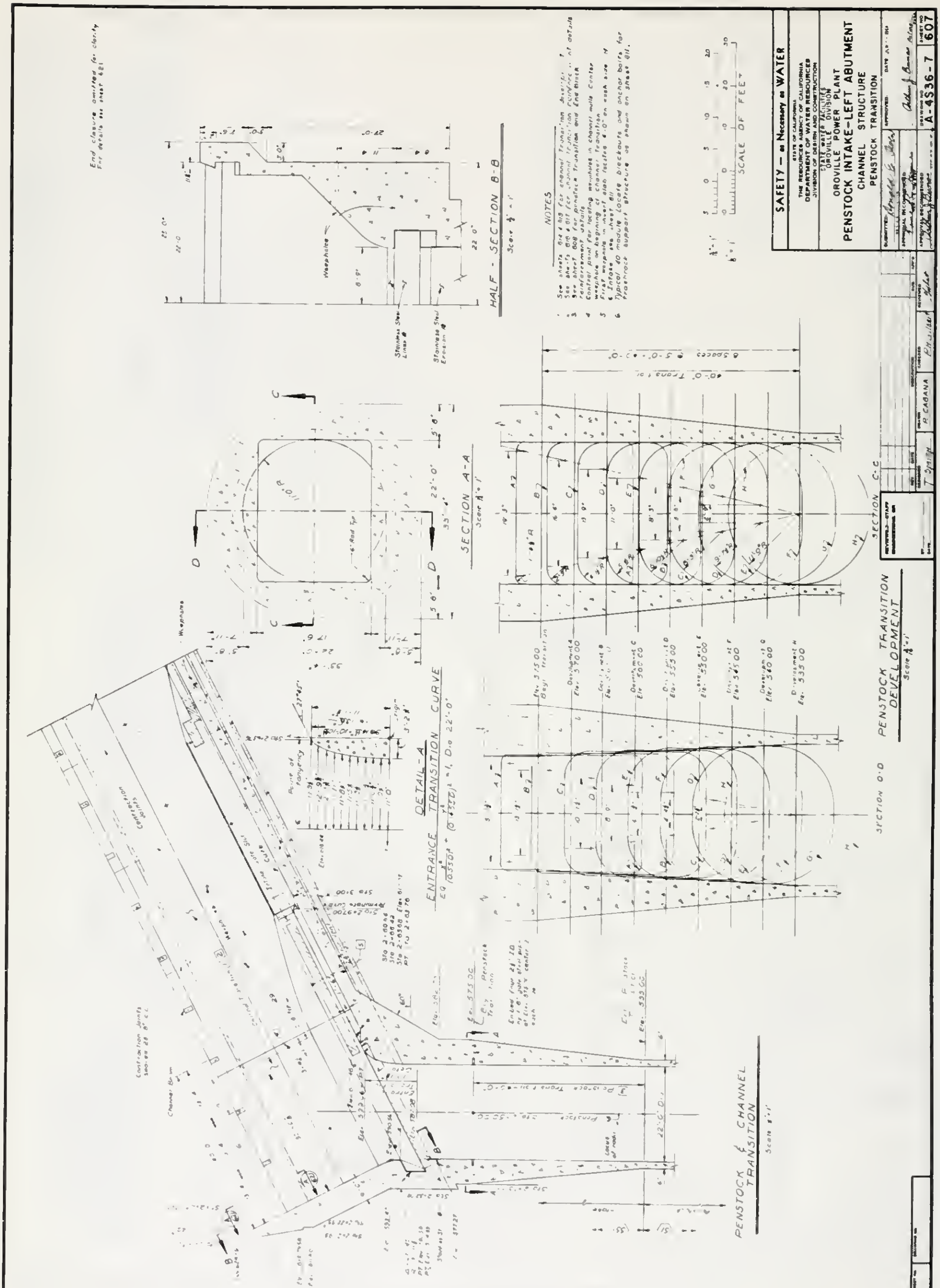

Figure 132. Penstock Transition

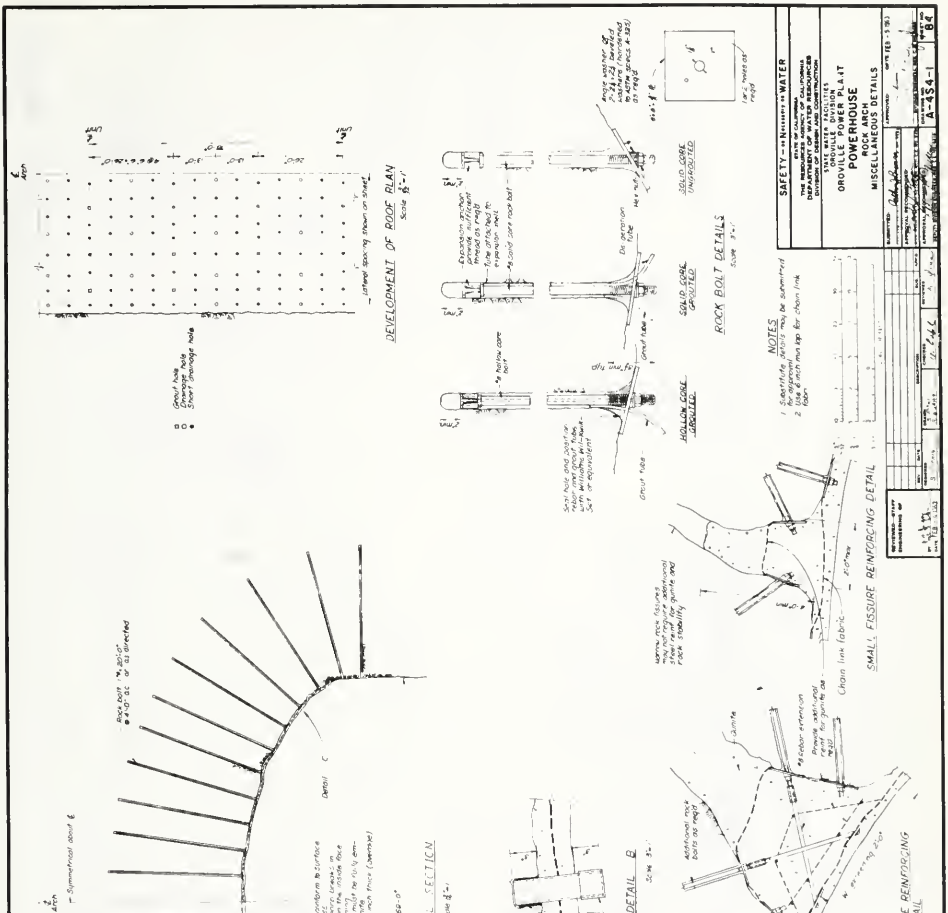

Figure 133. Rock Reinforcement

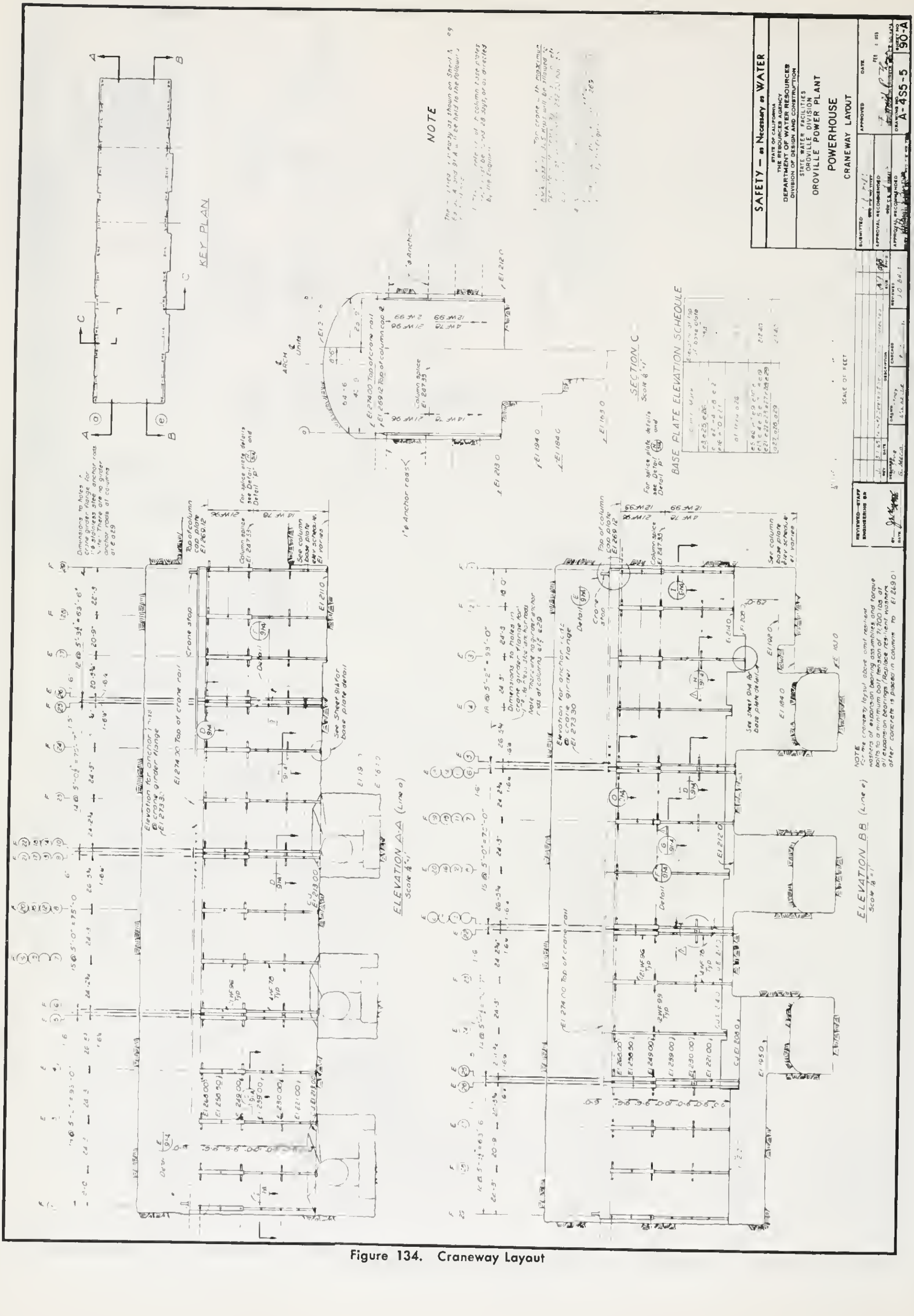

Figure 134. Craneway Layout

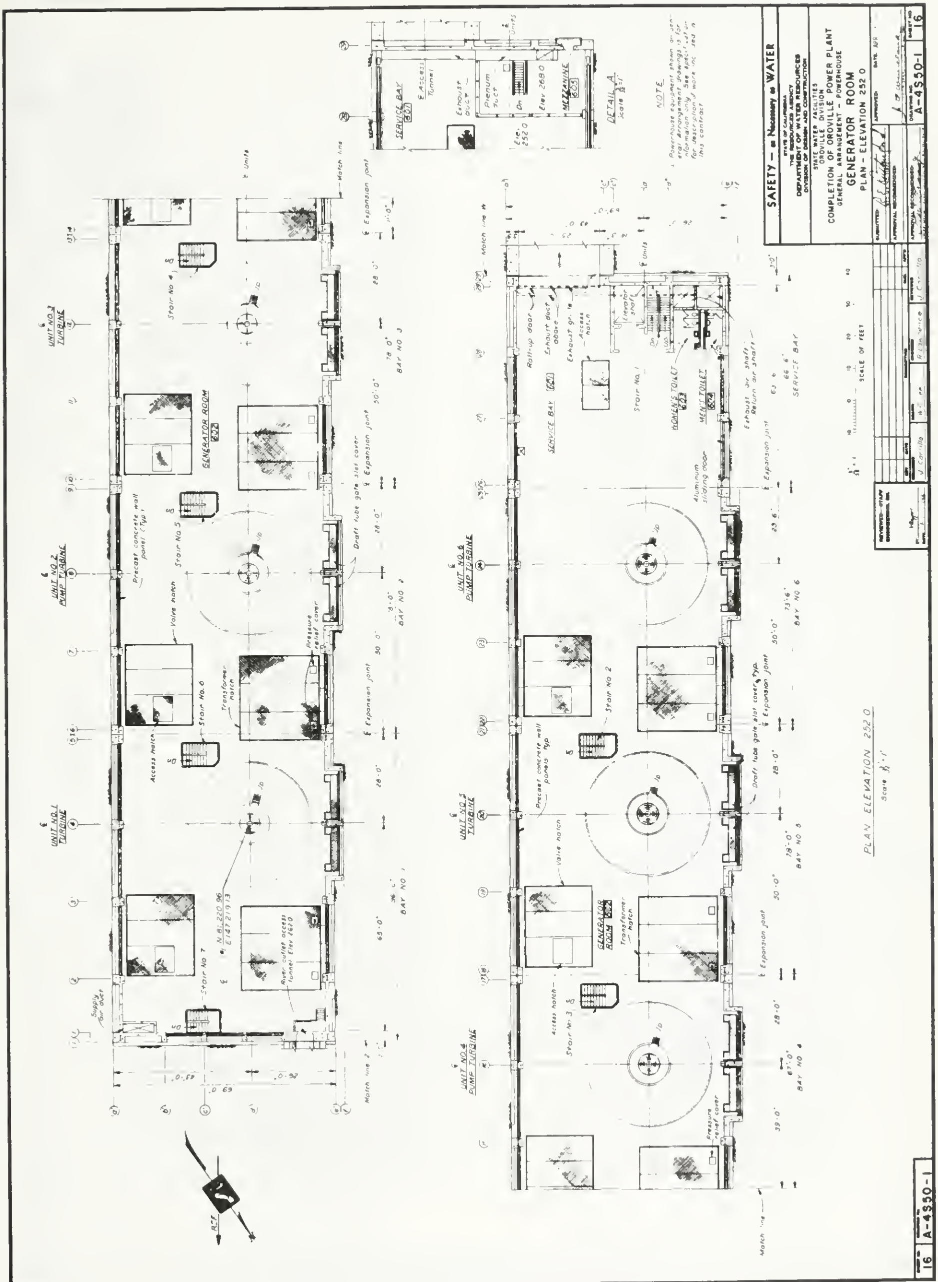

Figure 135. Generator Room—Plan—Elevotian 252.0

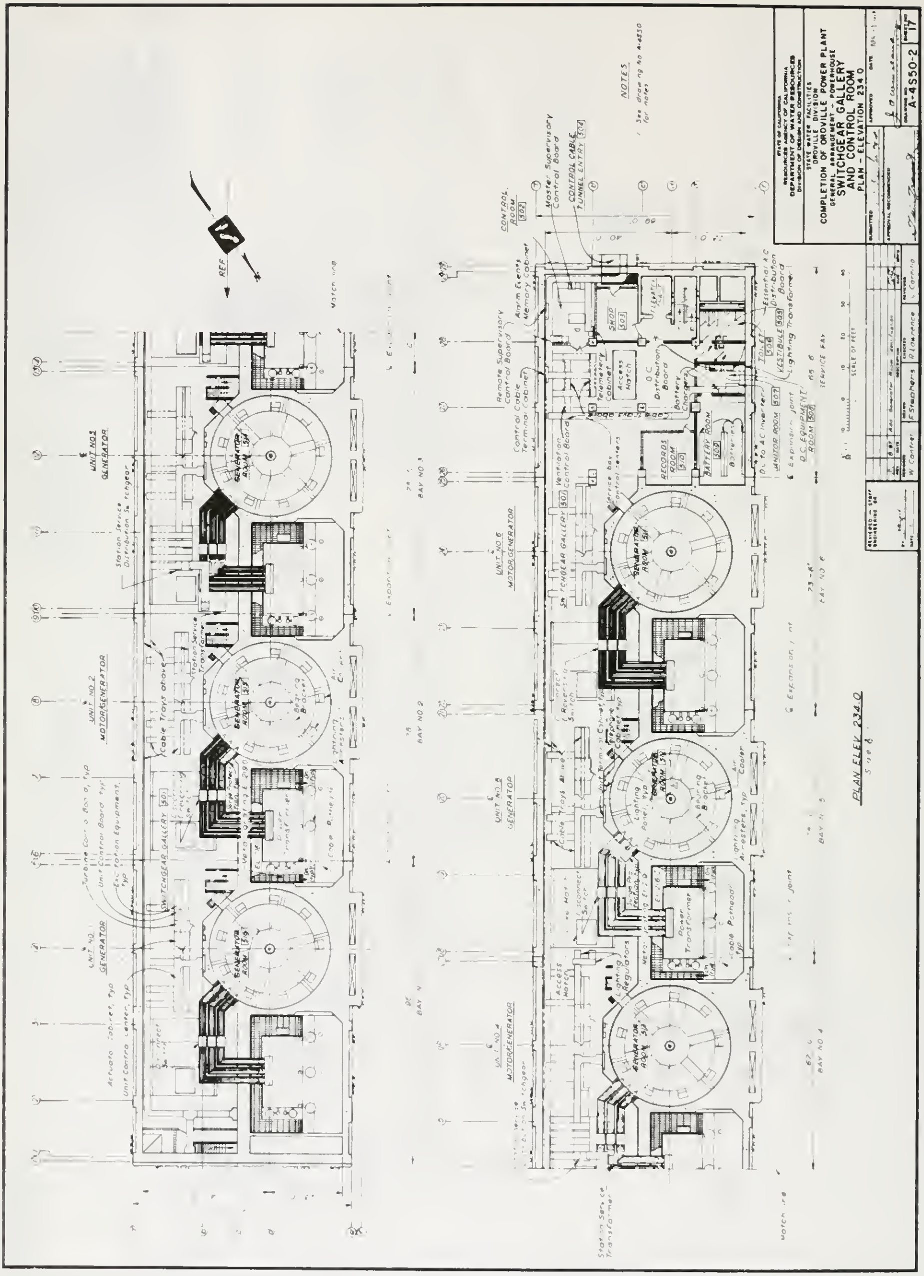

Figure 136. Switchgear Gallery—Plan—Elevation 234.0

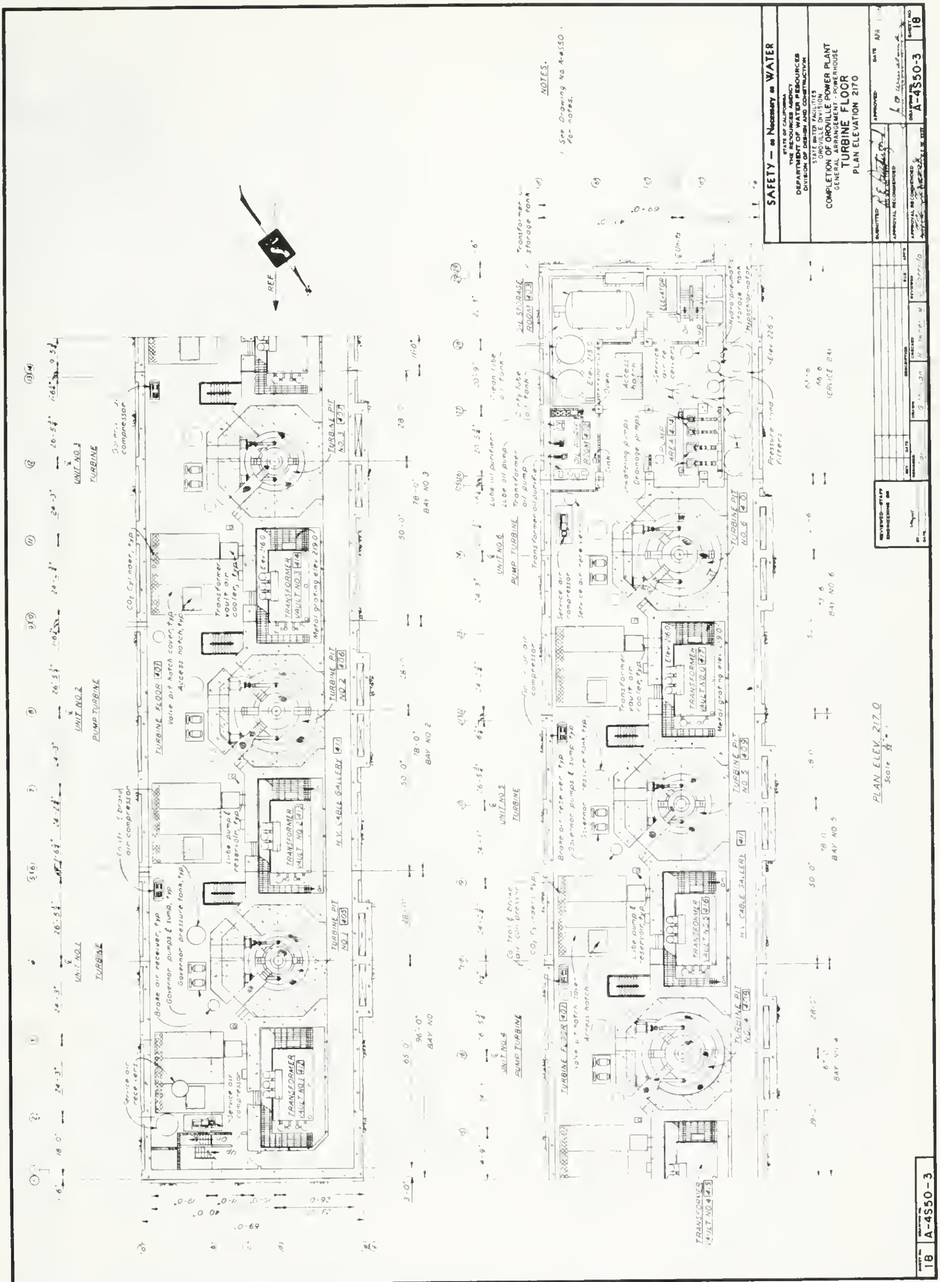

Figure 137. Turbine Floor—Plan—Elevation 217.0

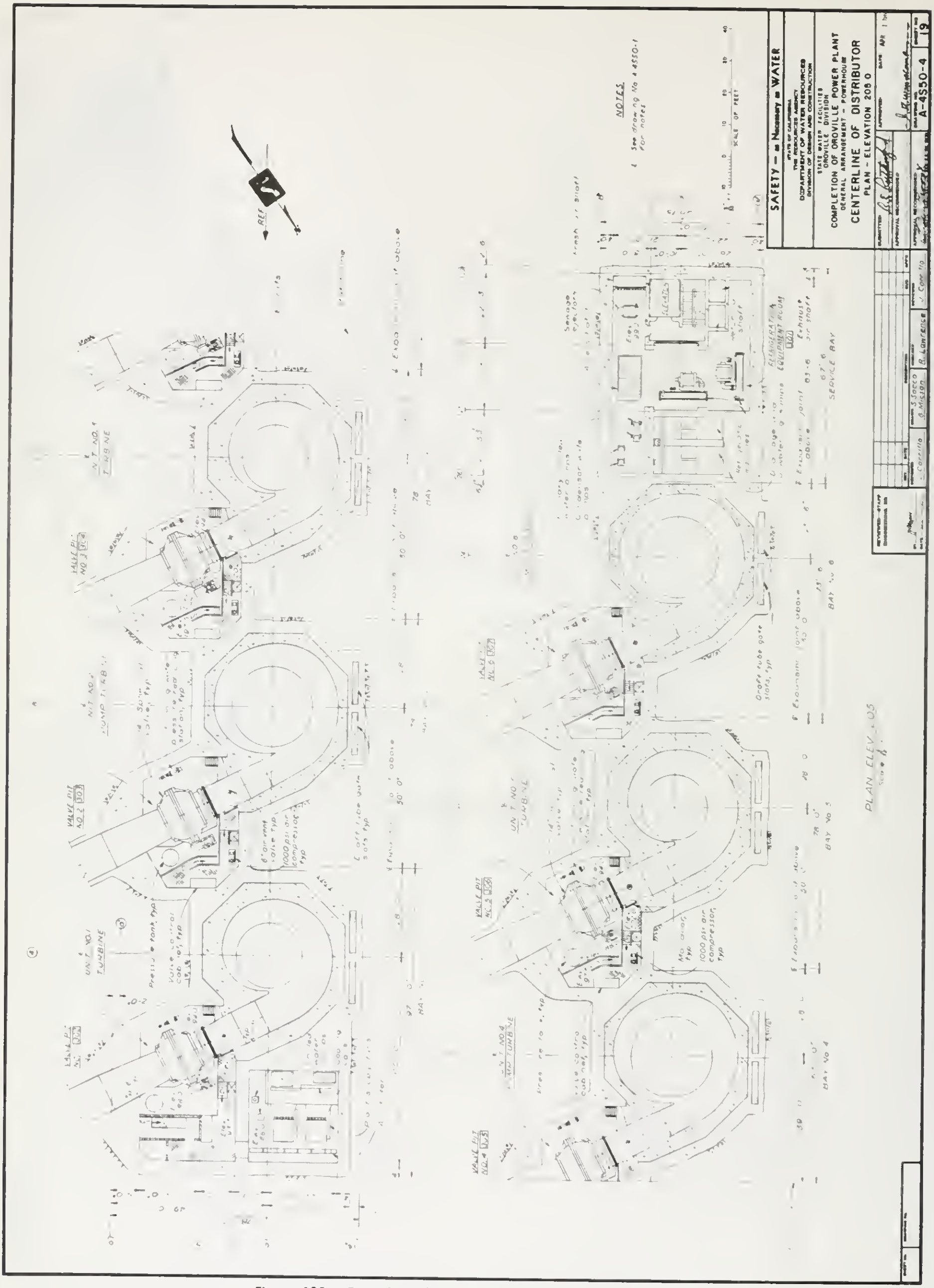

Figure 138. Centerline of Distributor—Plan—Elevation 205.0

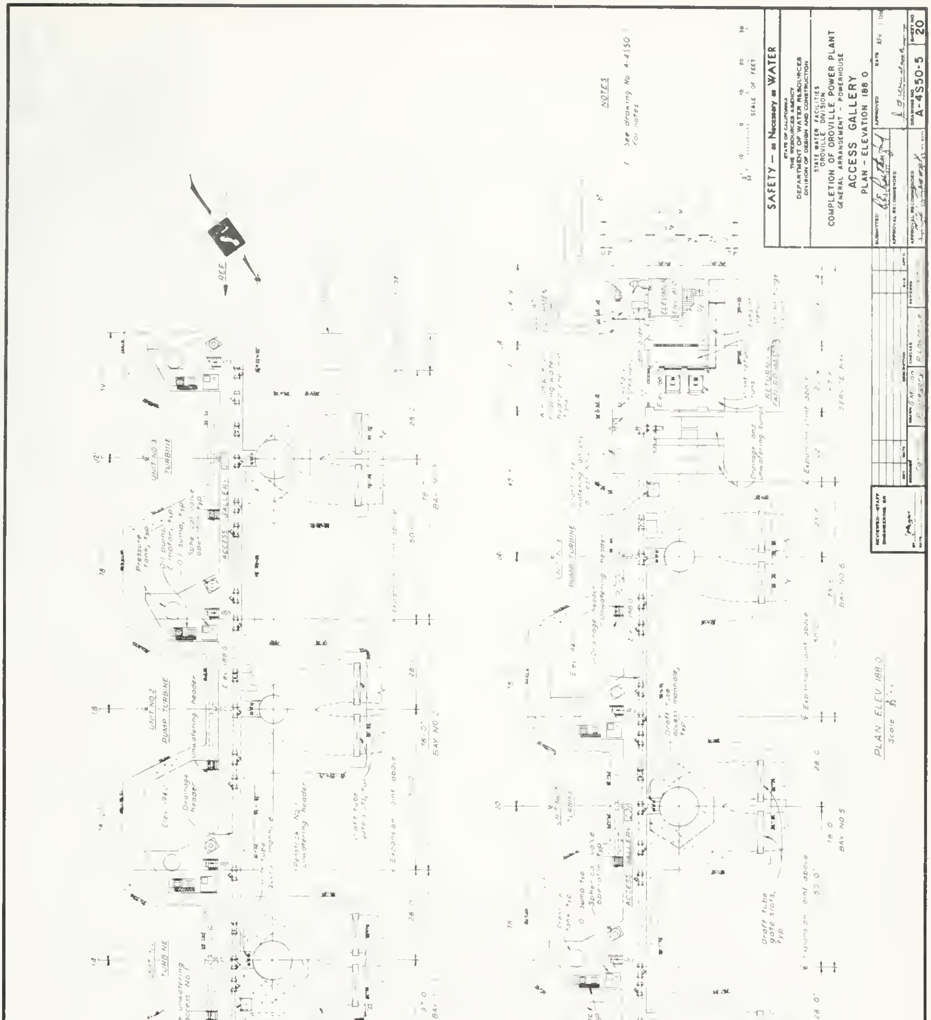

Figure 139. Access Gallery—Plan—Elevation 188.0

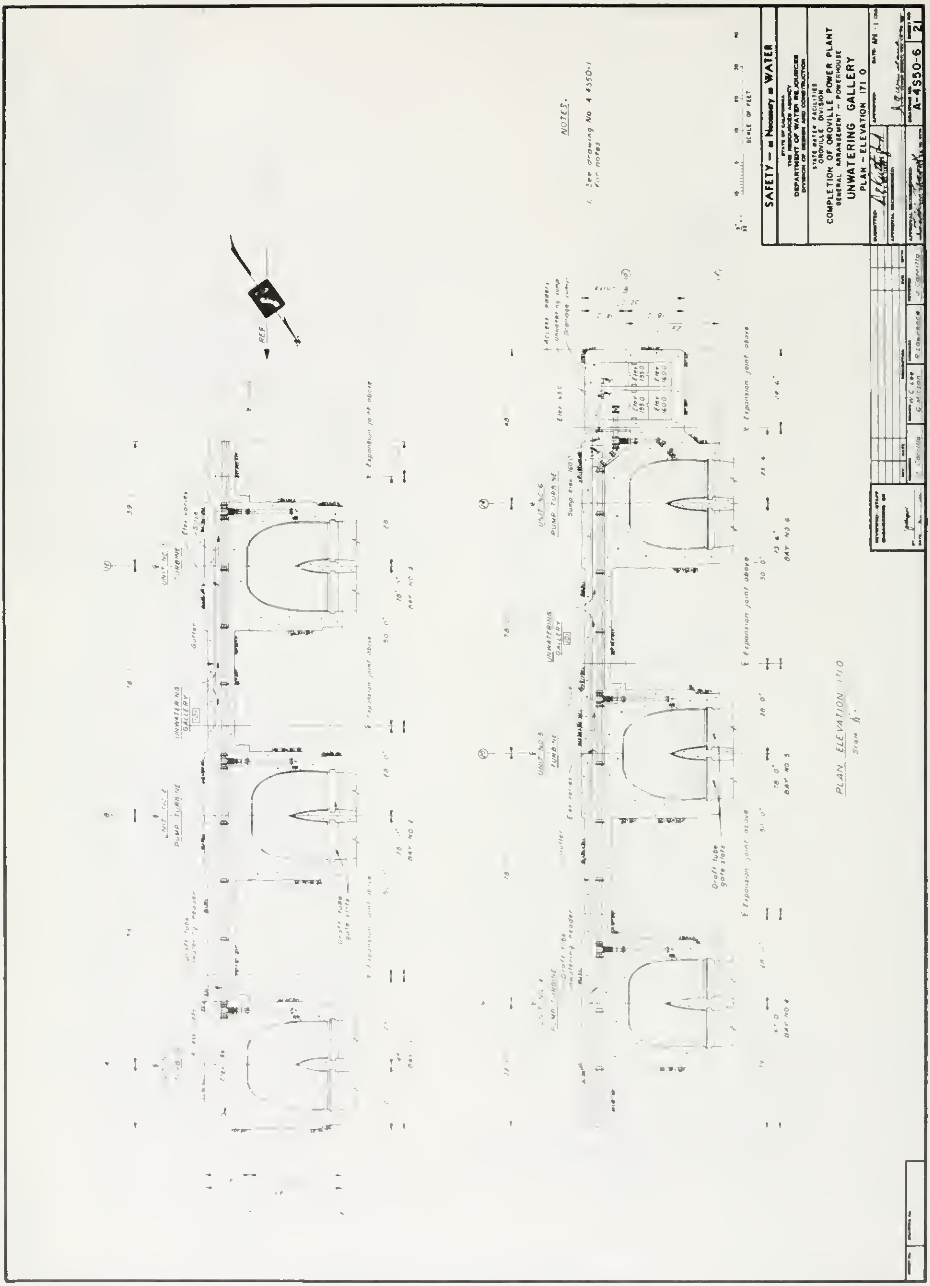

Figure 140. Dewatering Gallery—Plan—Elevation 171.0

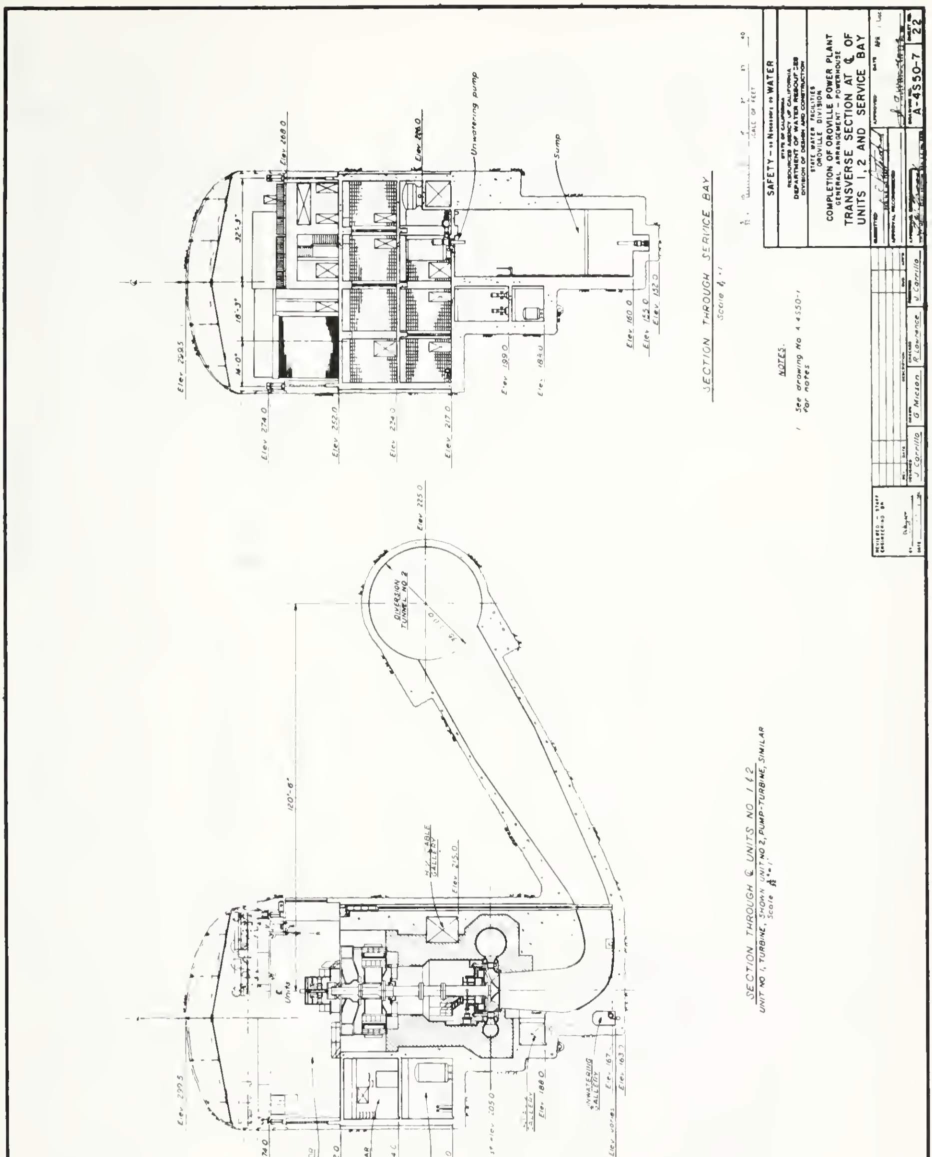

Figure 141. Transverse Section—Units Nos. 1 and 2

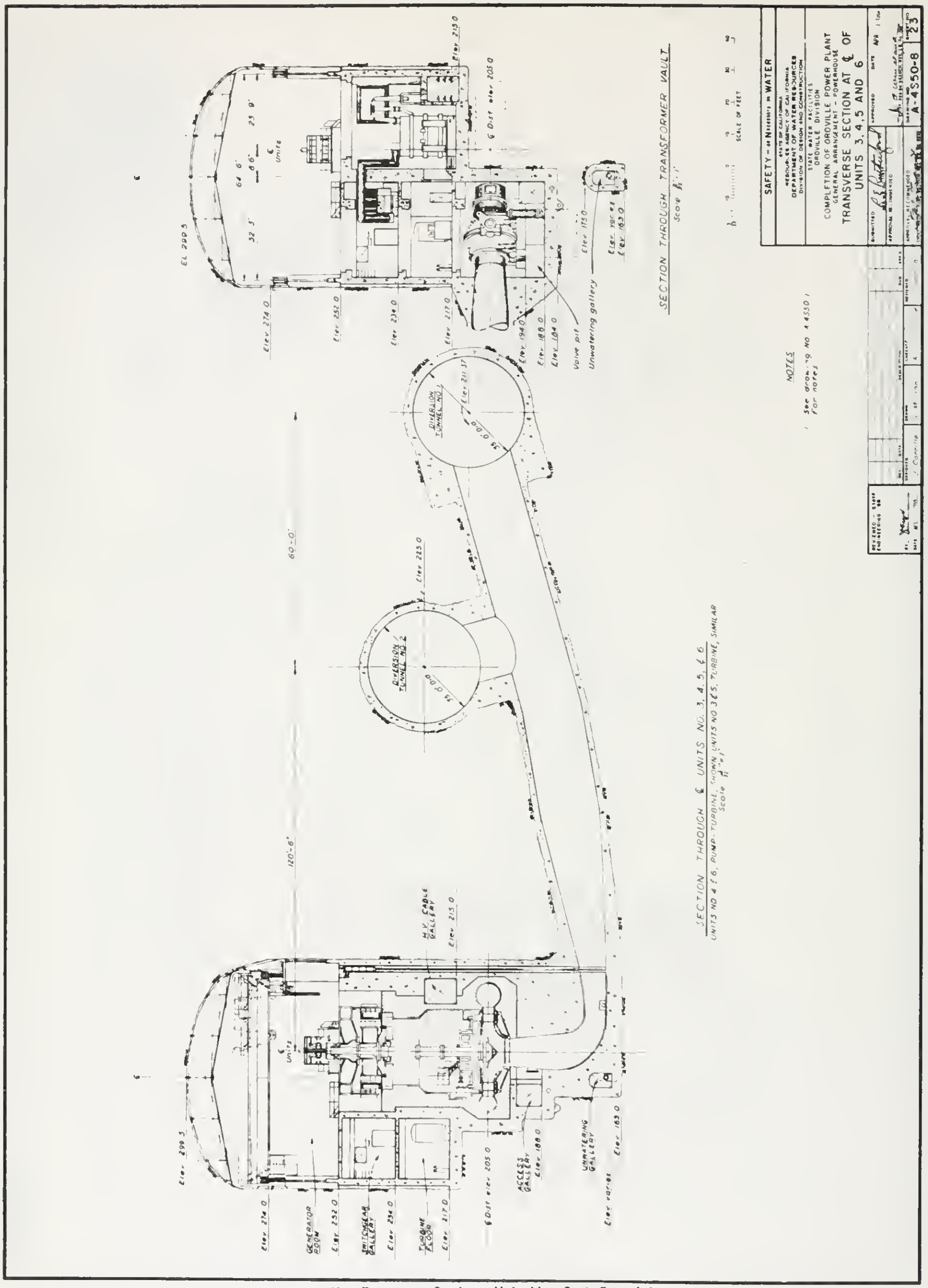

Figure 142. Transverse Section—Units Nos. 3, 4, 5, and 6

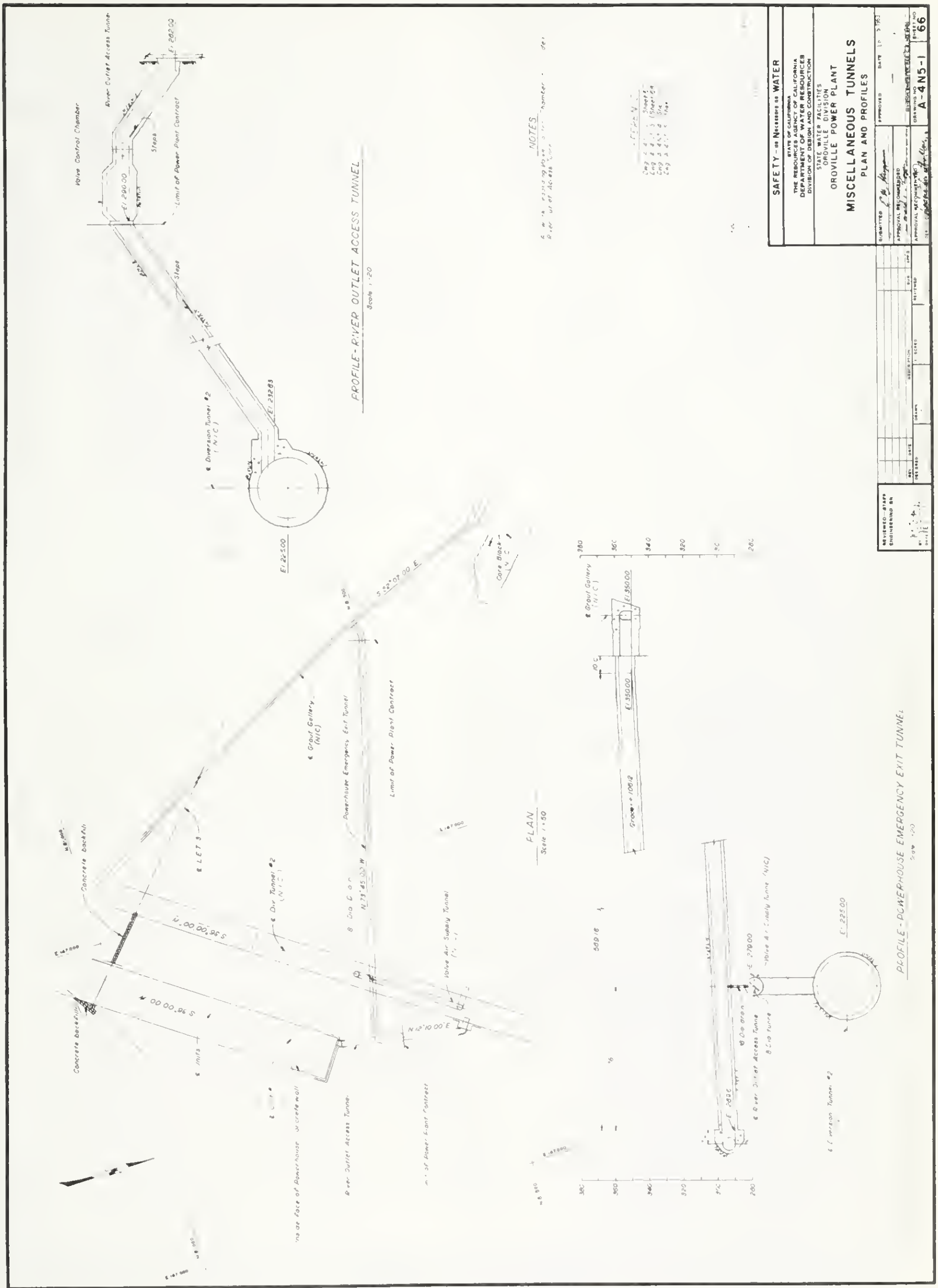

Figure 143. Miscellaneous Tunnels

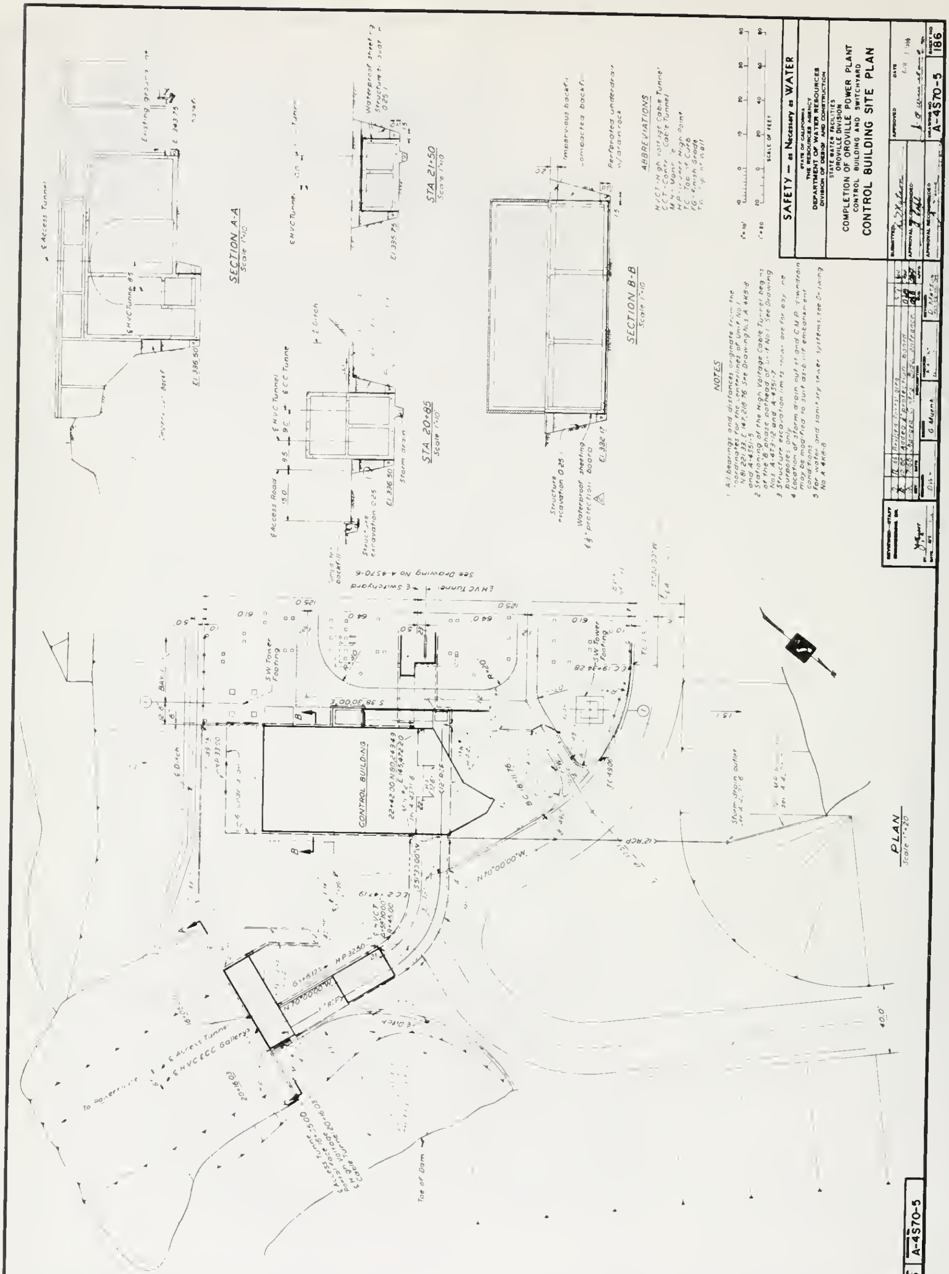

Figure 144. Control Building Site Plan

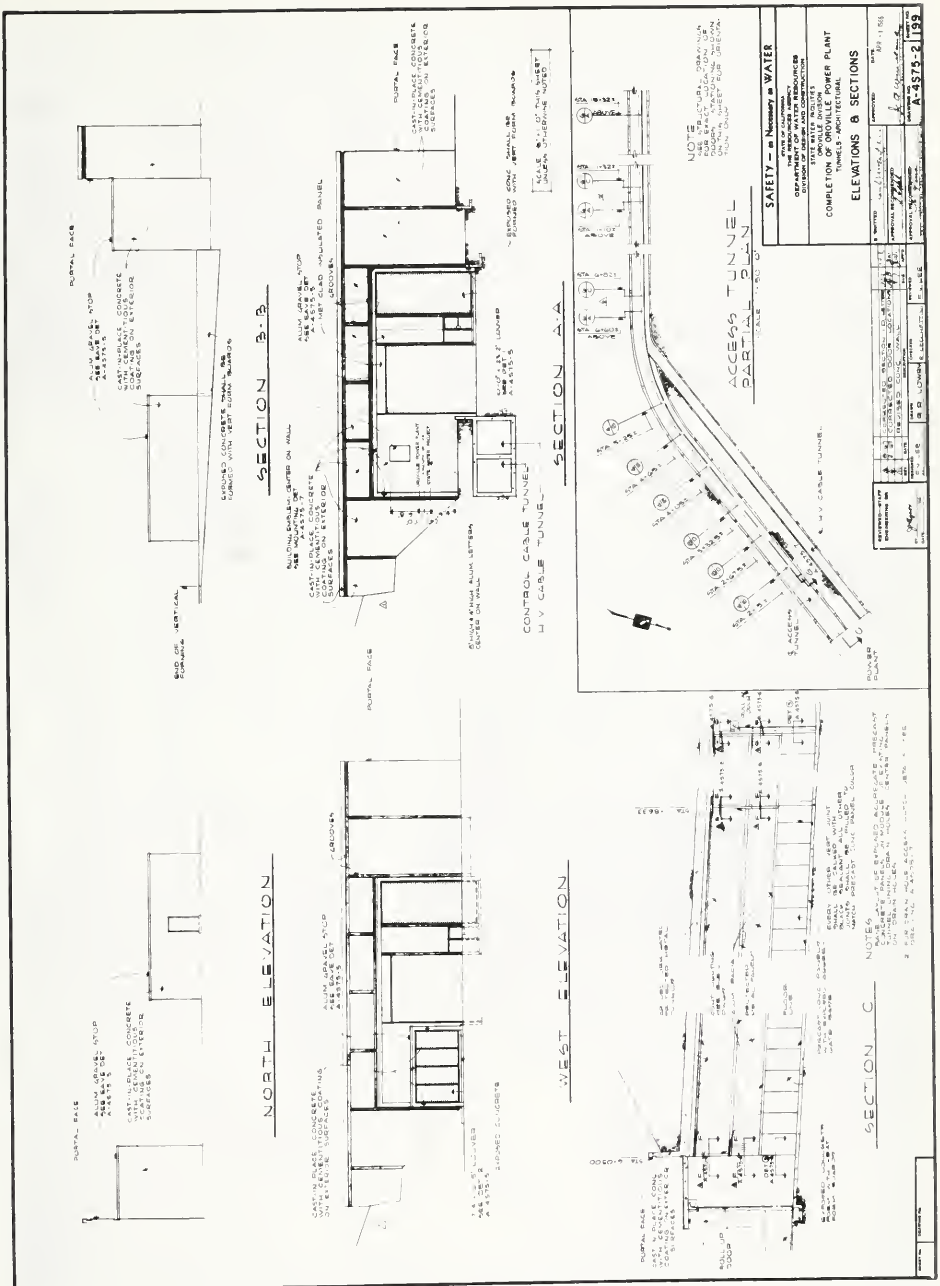

Figure 145. Tunnels—Architectural

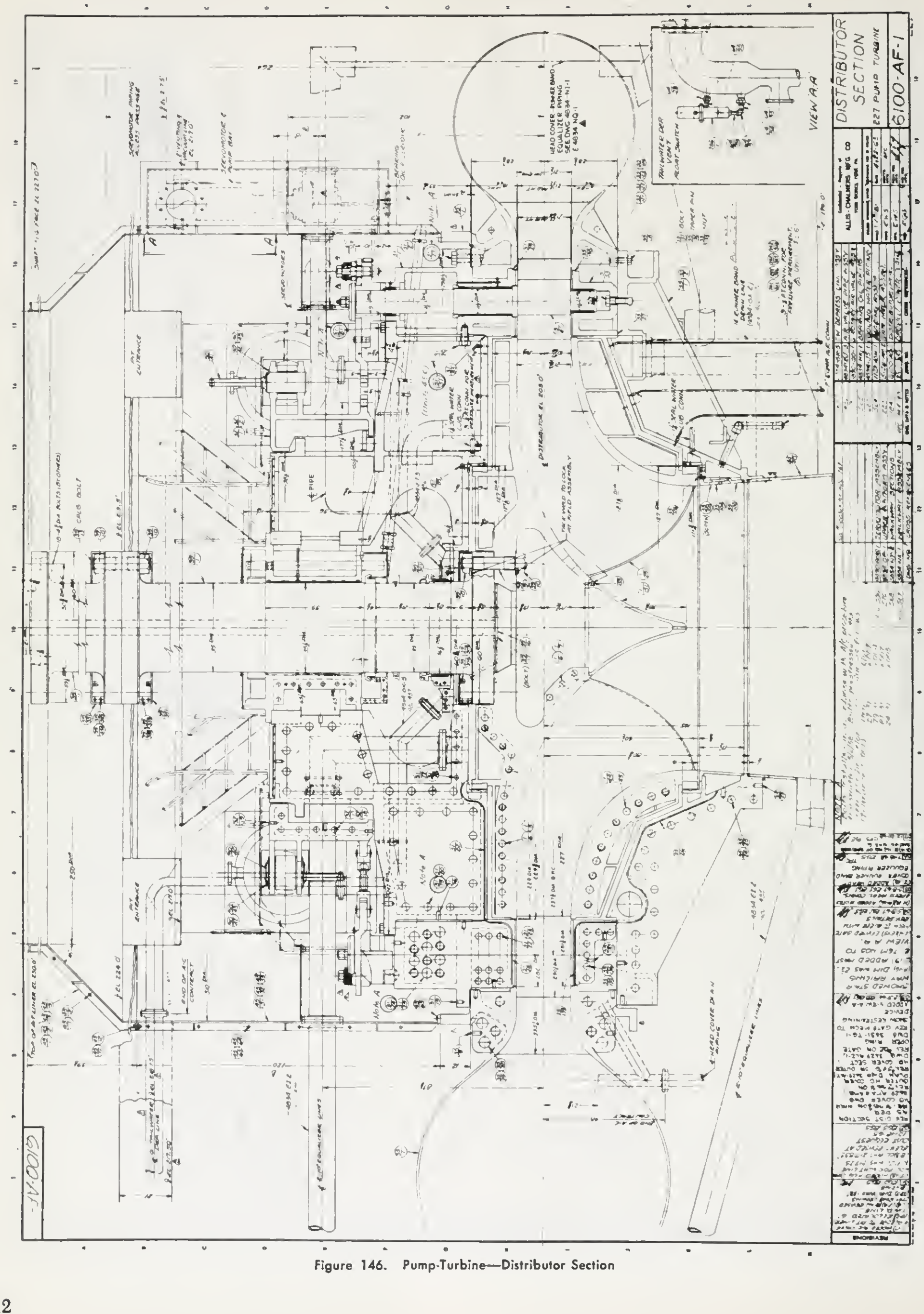

Figure 146. Pump-Turbine—Distributor Section

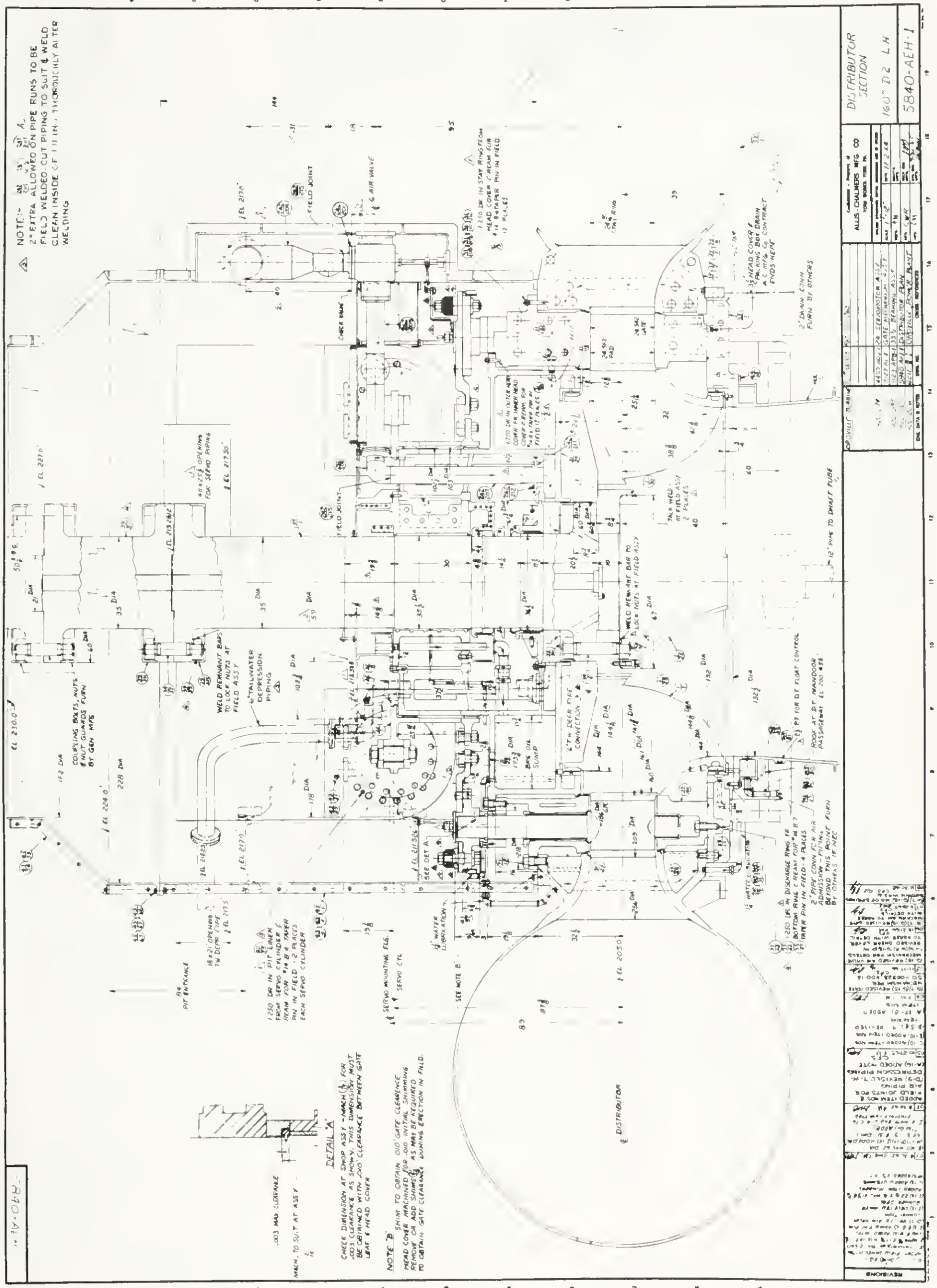

Figure 147. Turbine—Distributor Section

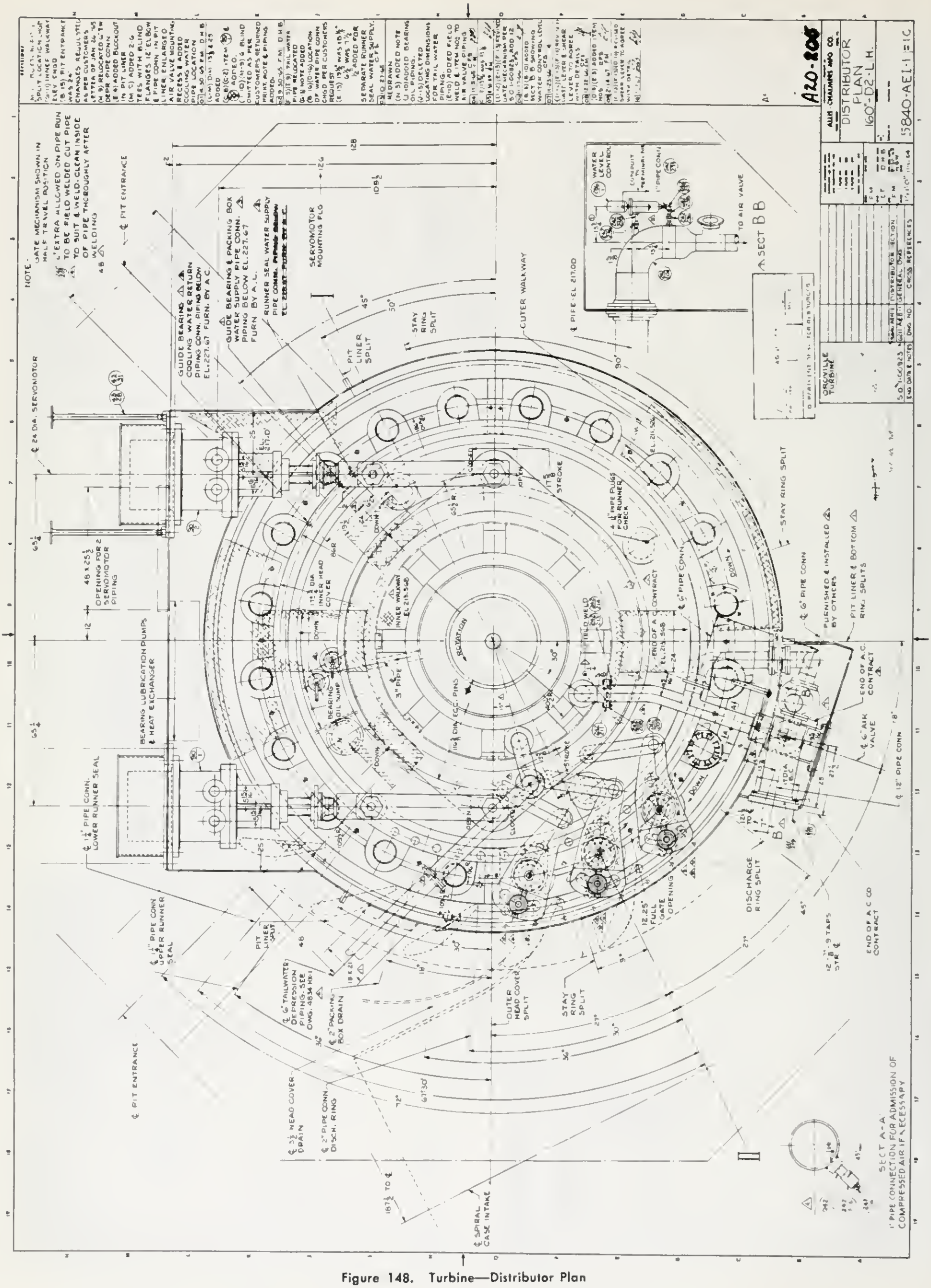

Figure 148. Turbine—Distributor Plan

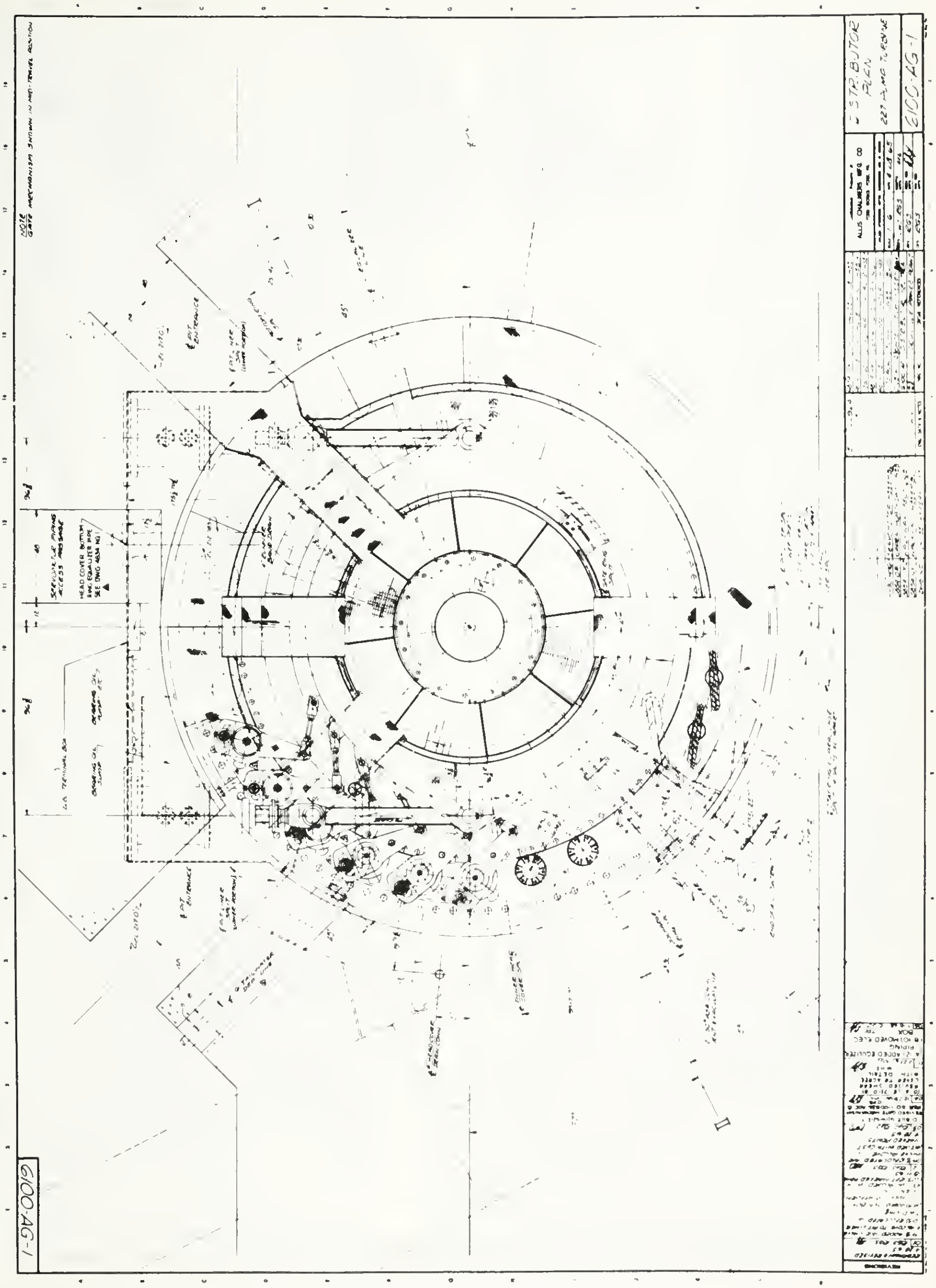

Figure 149. Pump-Turbine—Distributor Plan

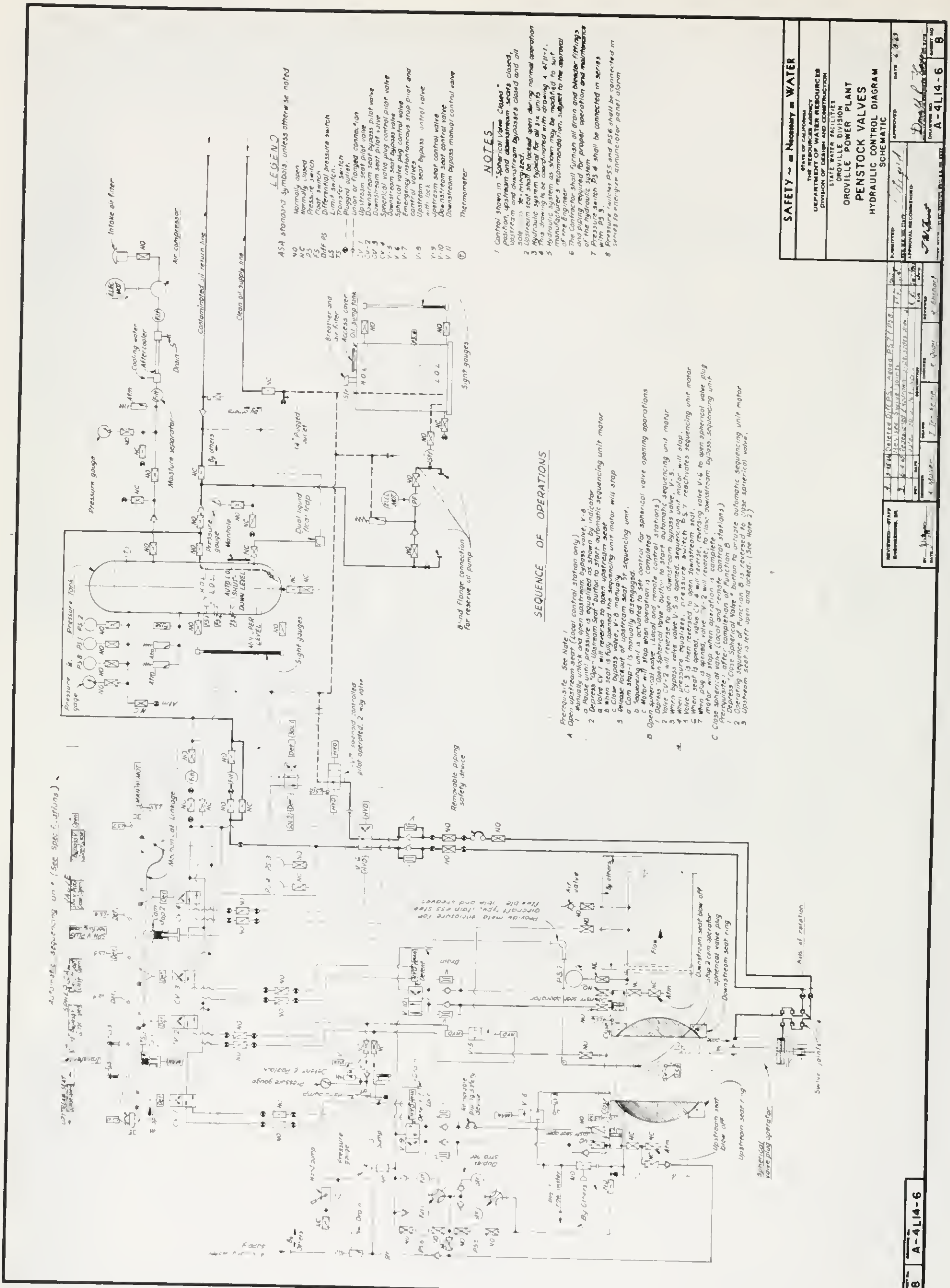

Figure 150. Penstock Valve—Hydraulic Control Diagram

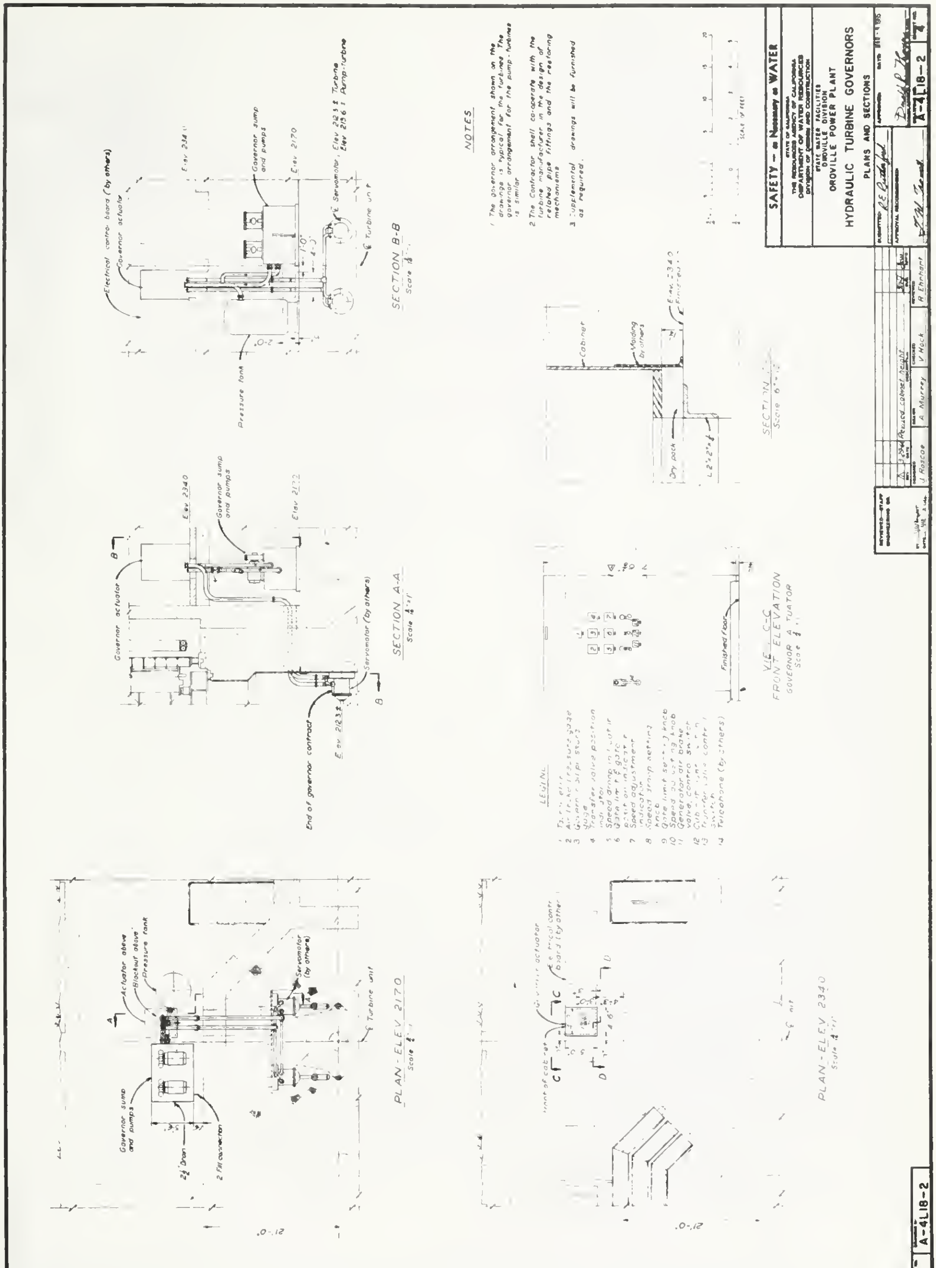

Figure 151. Hydraulic Turbine Governors

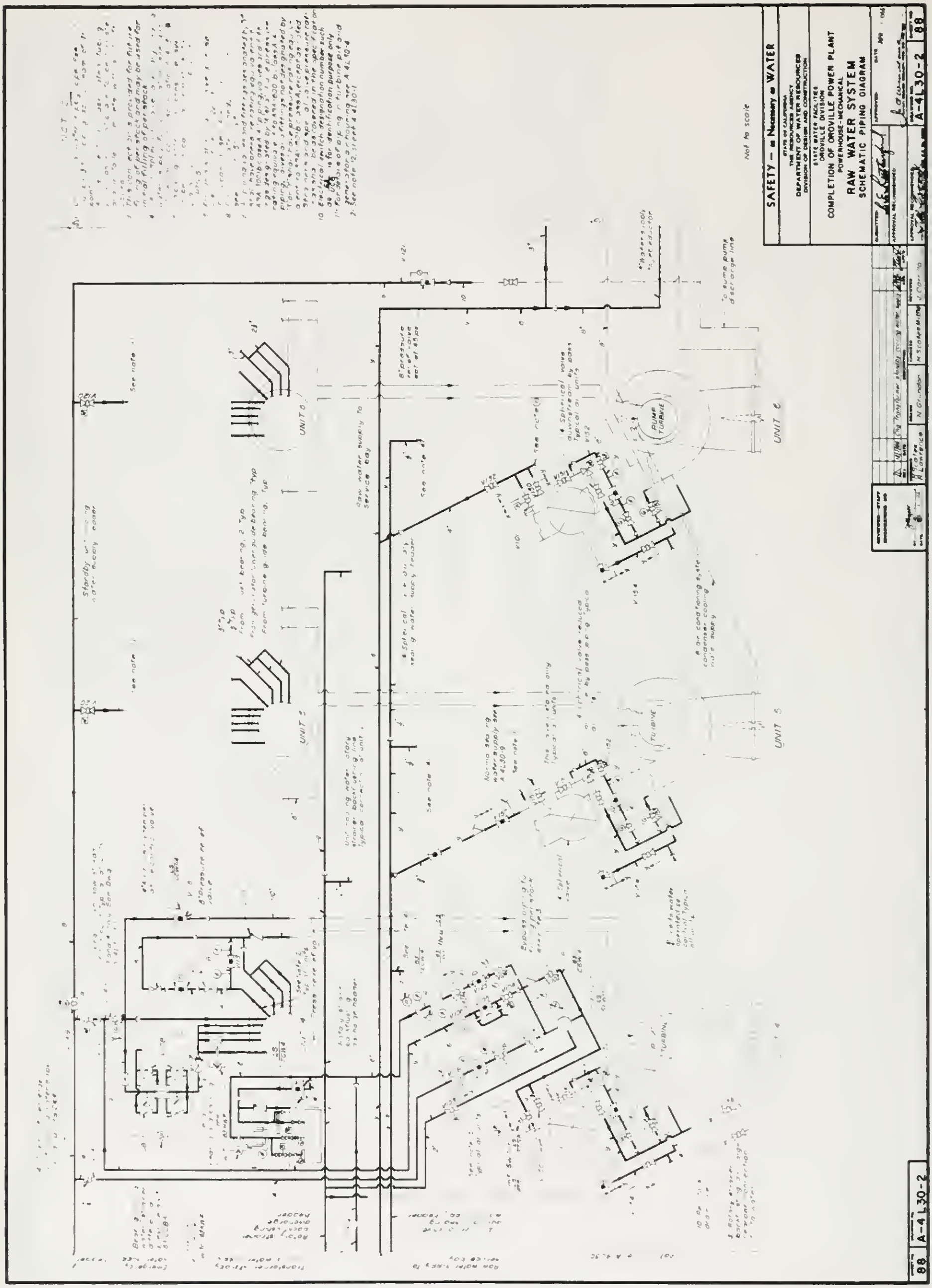

Figure 152. Raw Water System

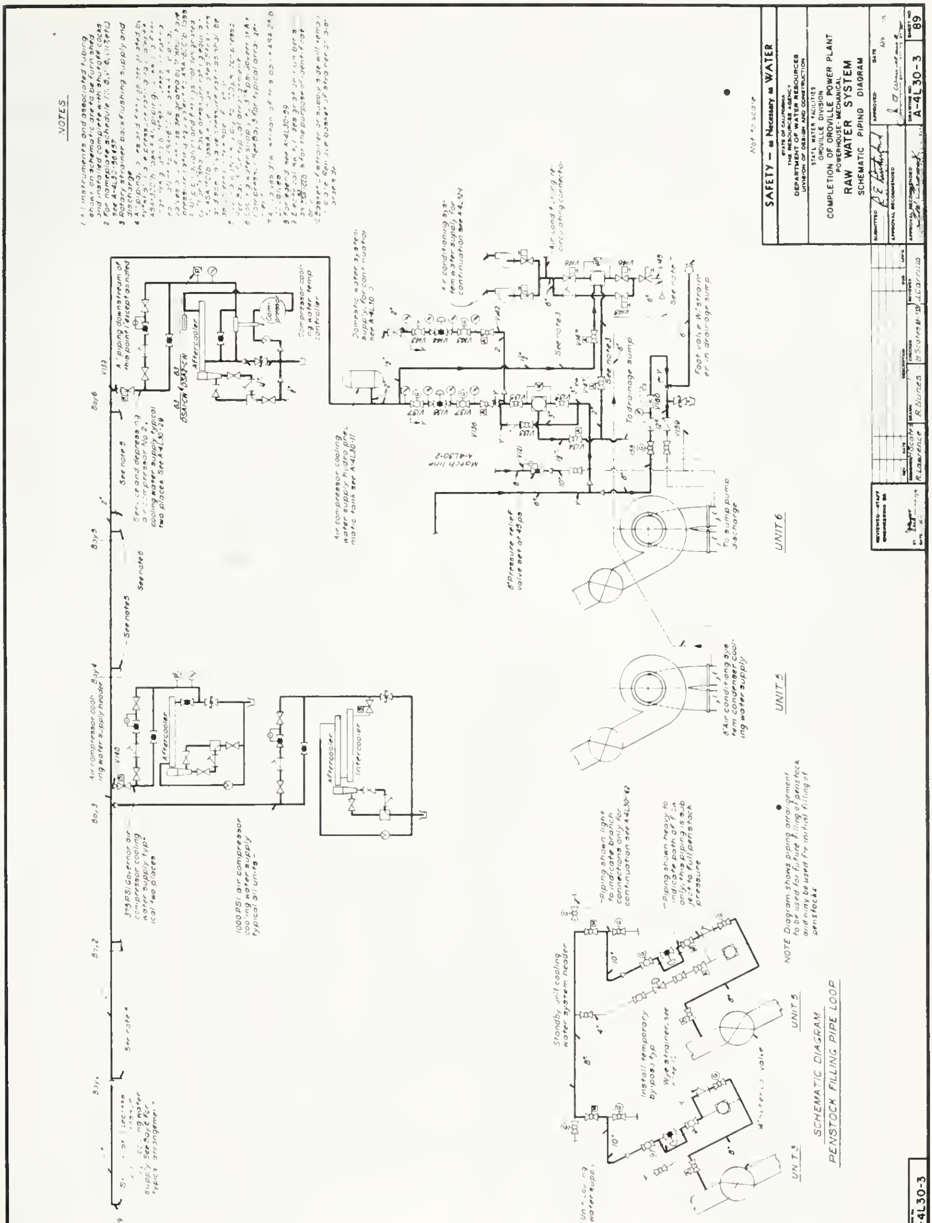

Figure 153. Raw Water System (Continued)

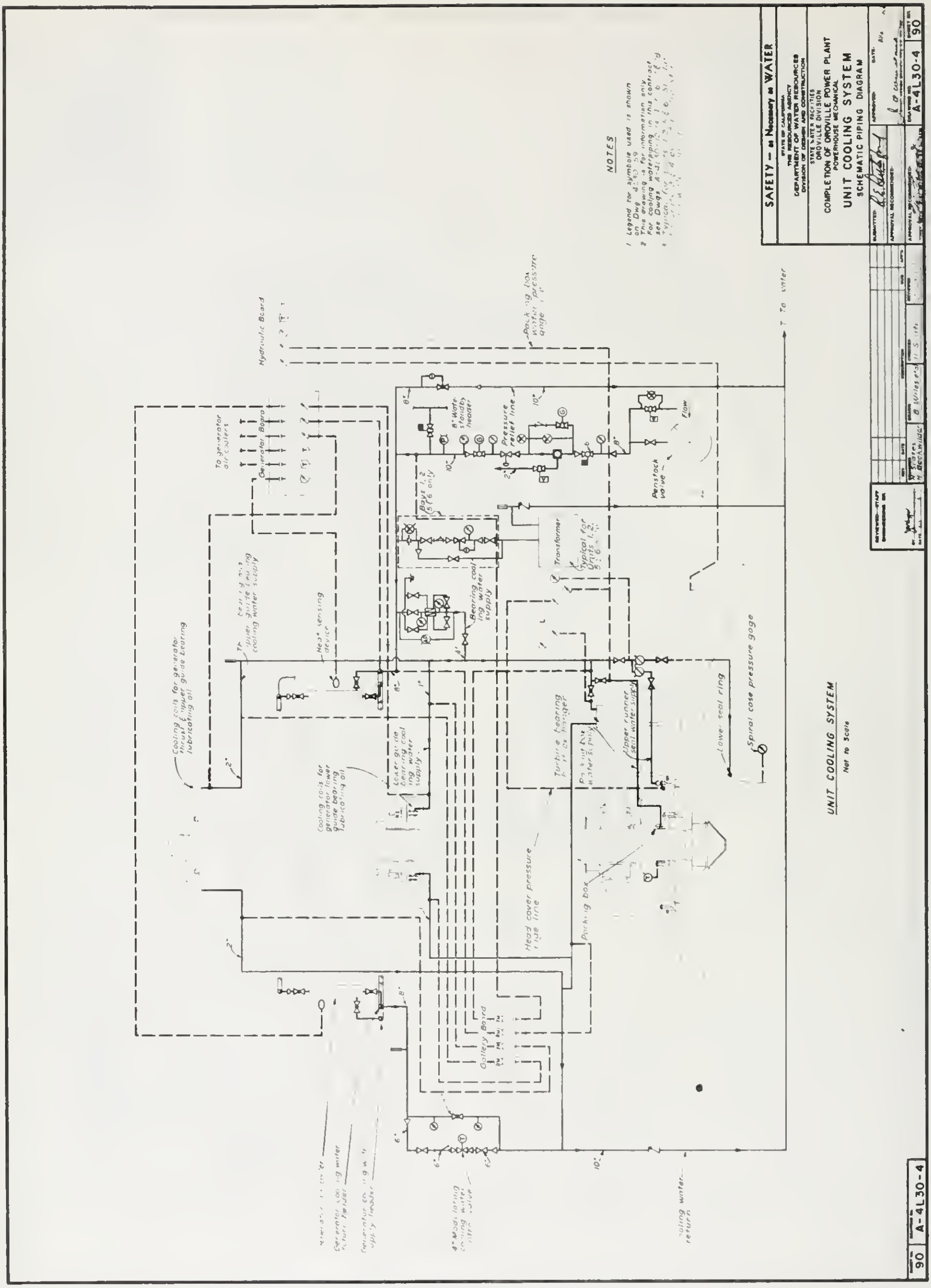

Figure 154. Unit Cooling System

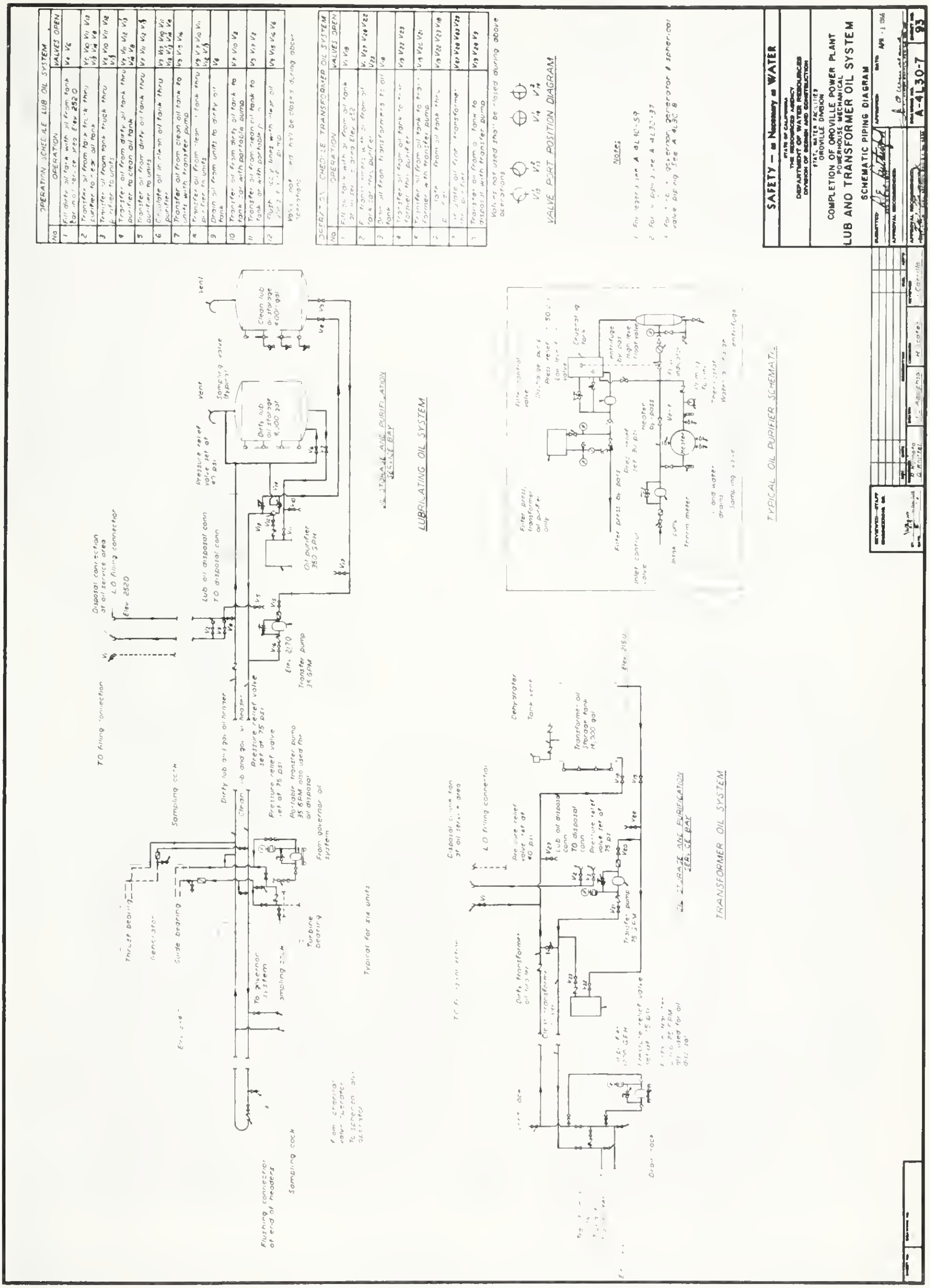

Figure 155. Lube and Transformer Oil System

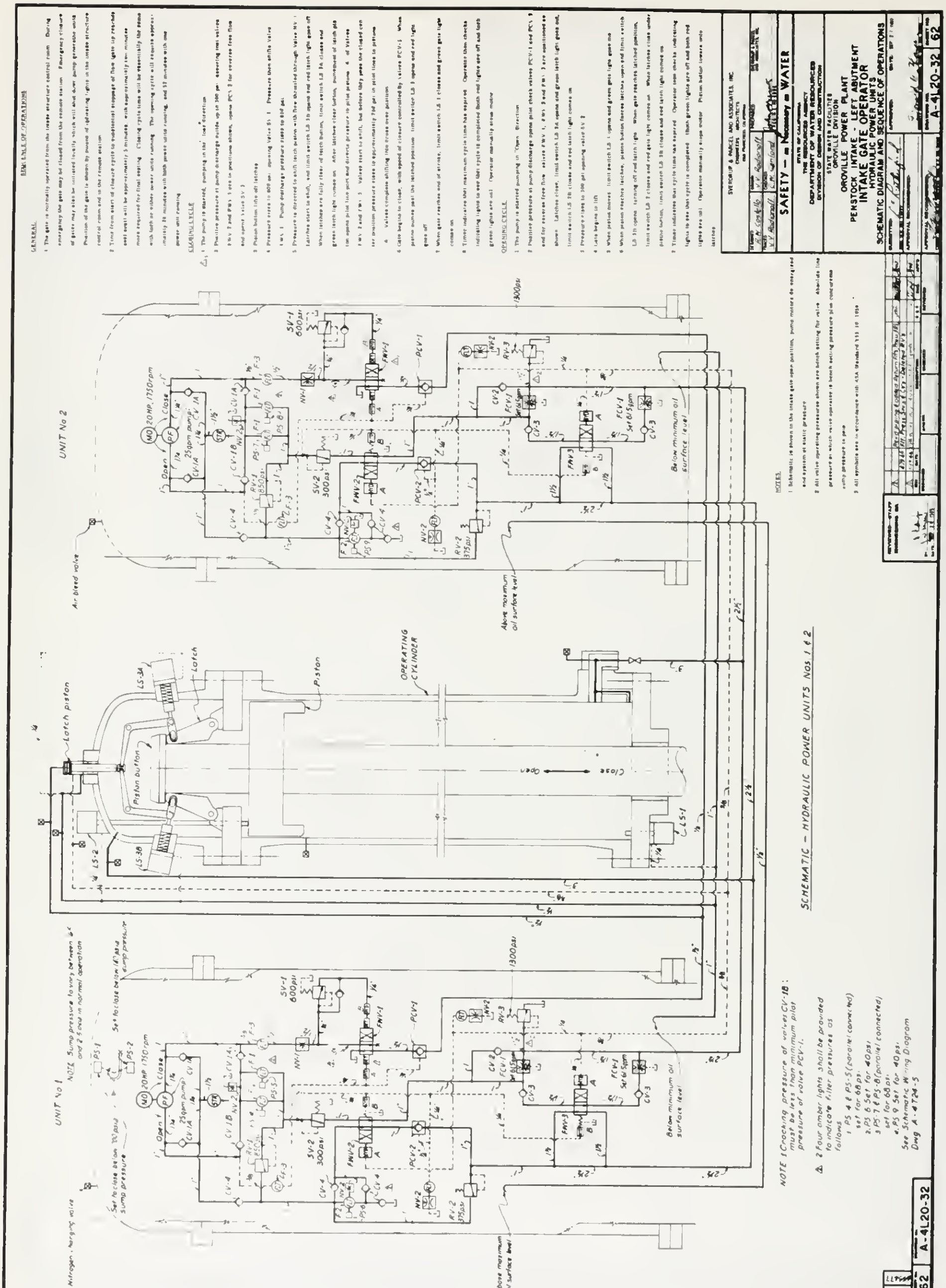

Figure 156. Intake Gate Operator—Hydraulic Control Diagram

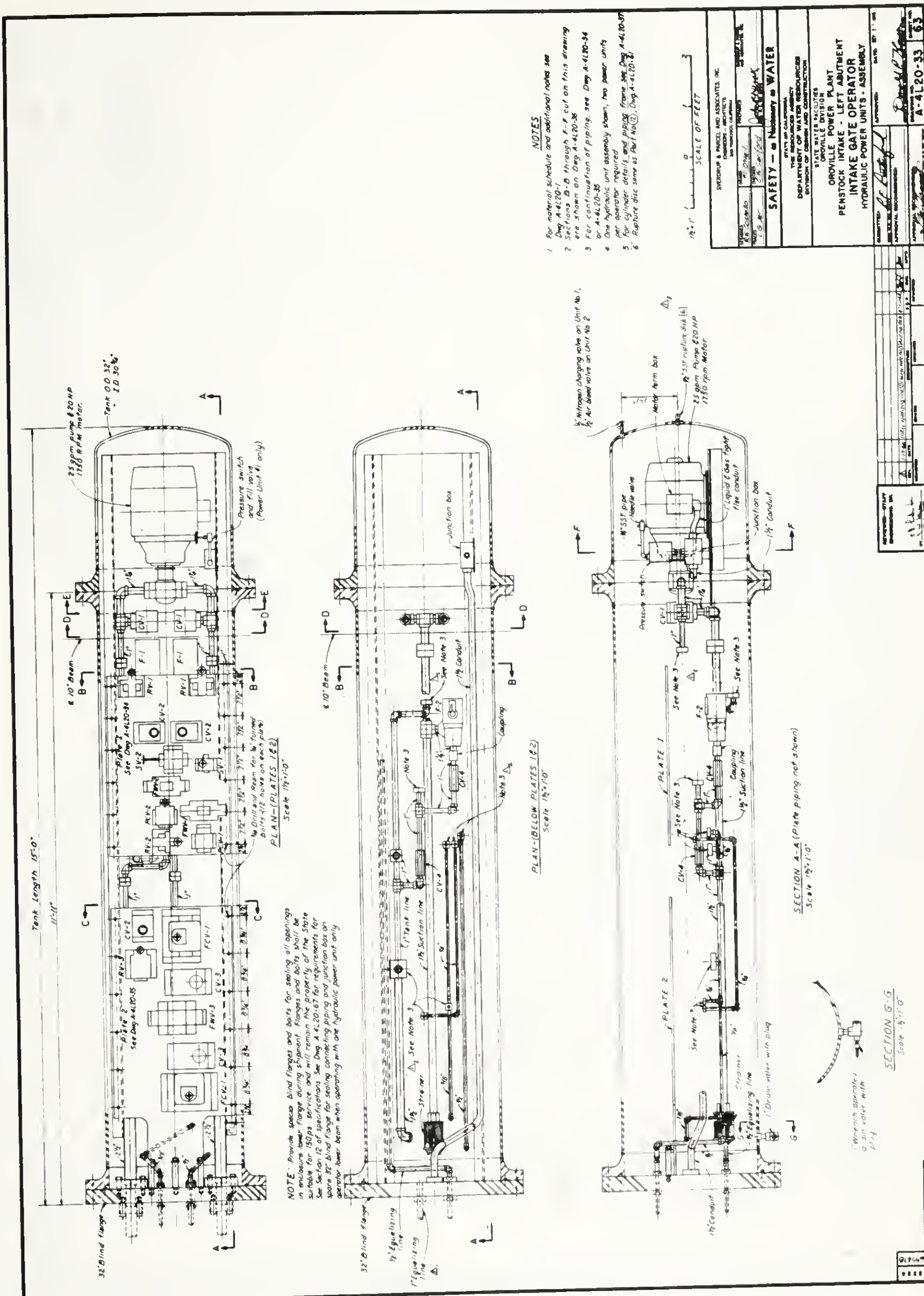

Figure 157. Intake Gate Operator—Power Unit

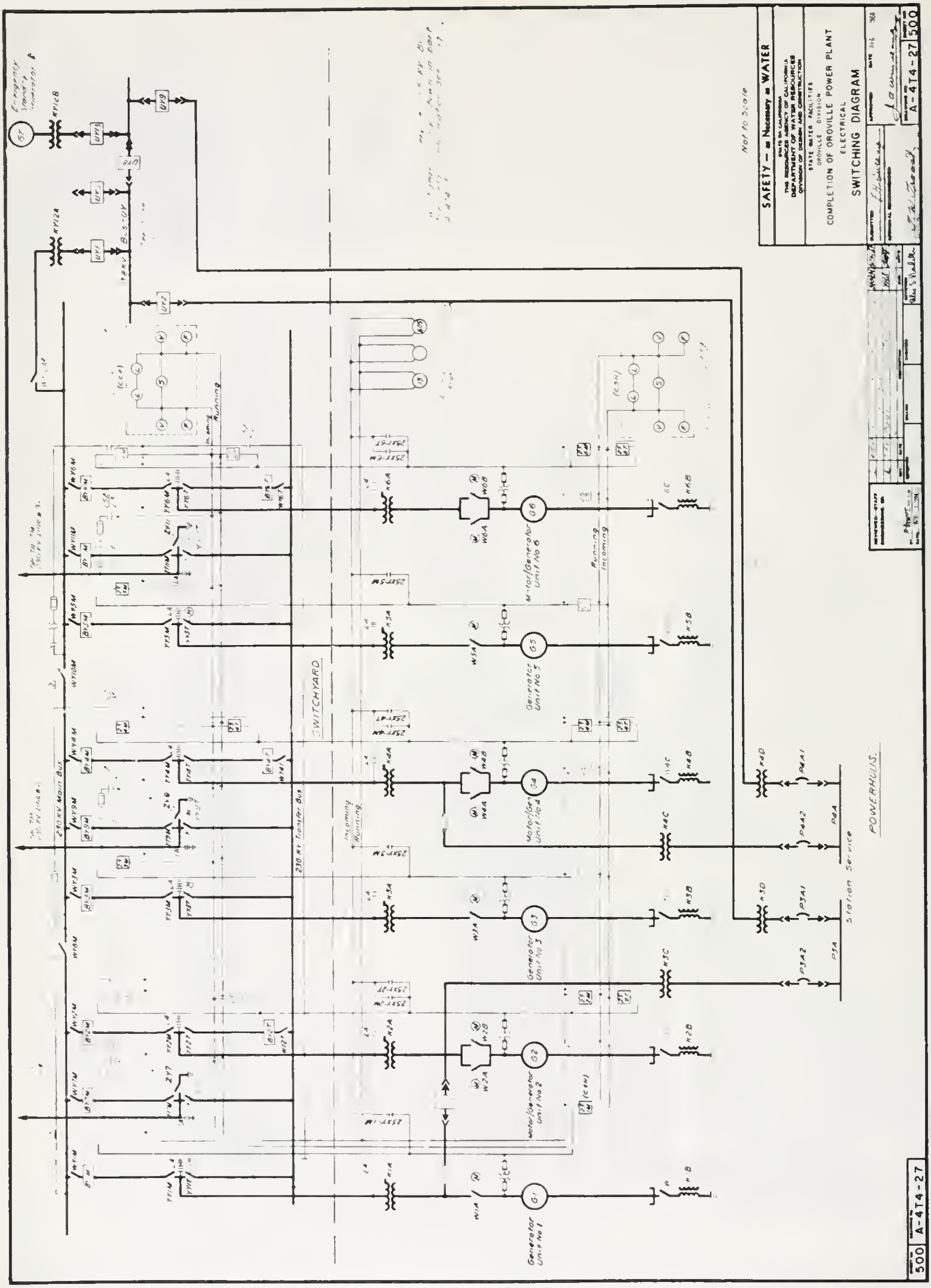

Figure 158. Plant Switching Diagram

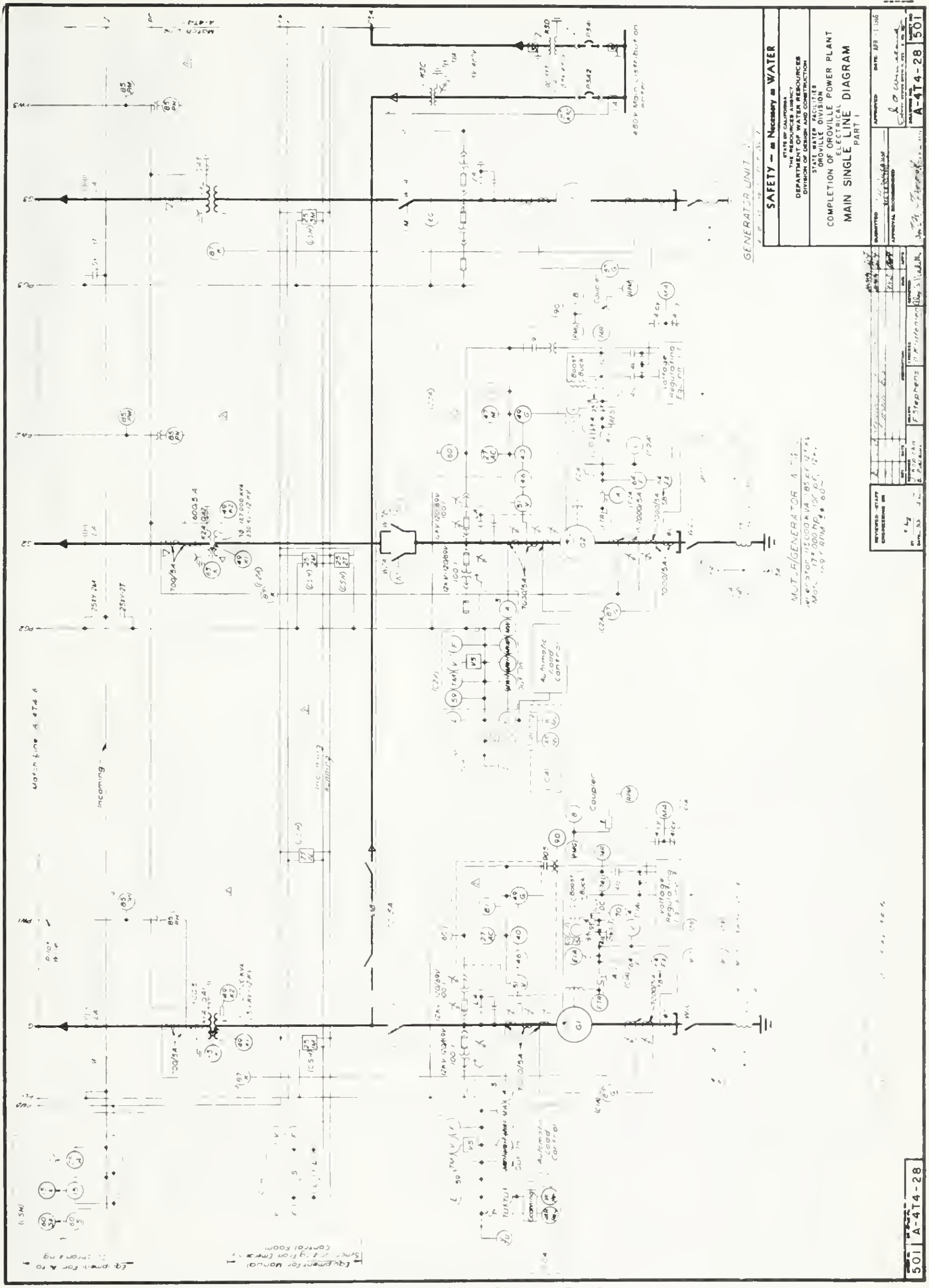

Figure 159. Single-Line Diagram—Part 1

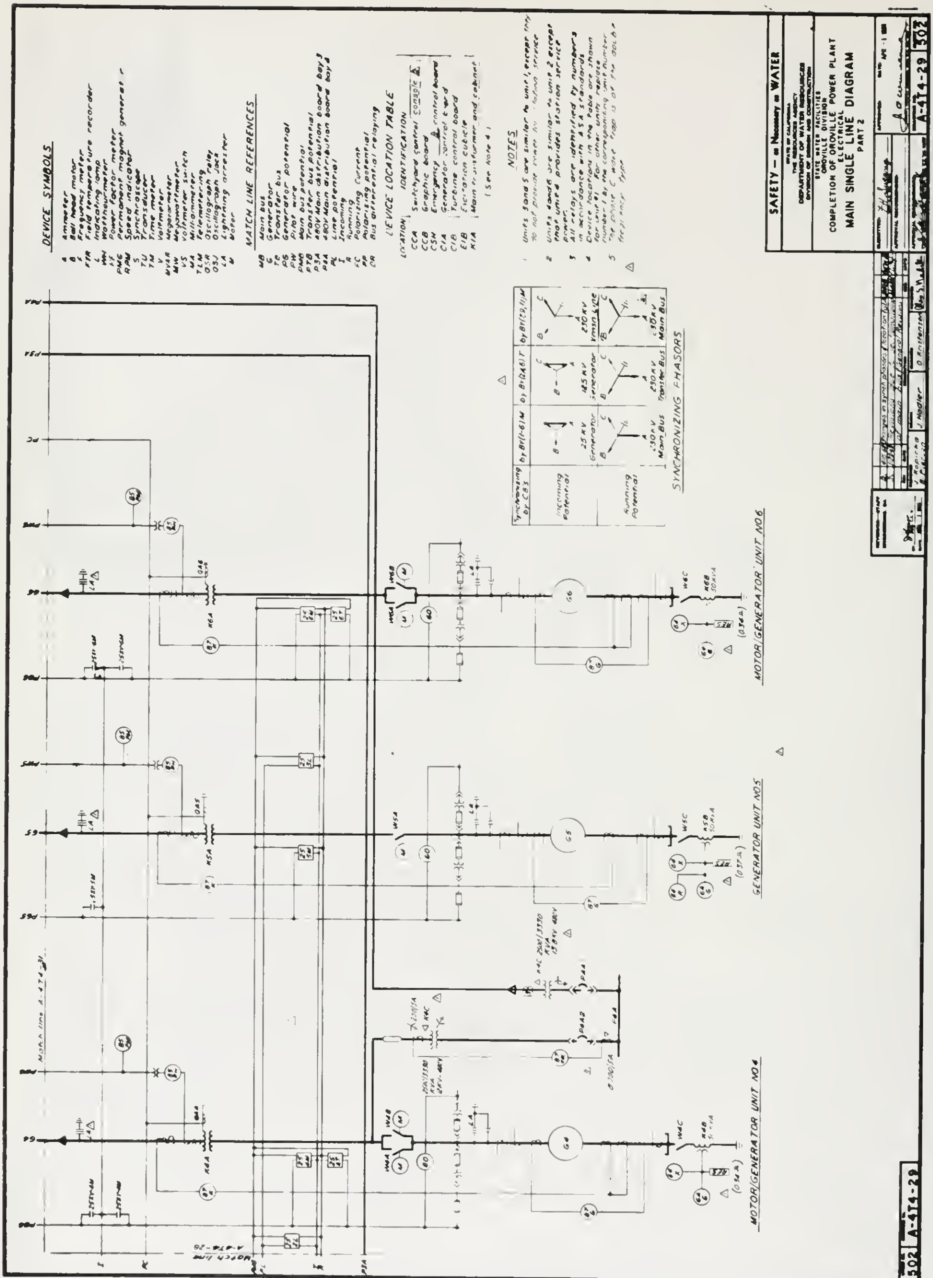

Figure 160. Single-Line Diagram—Part 2

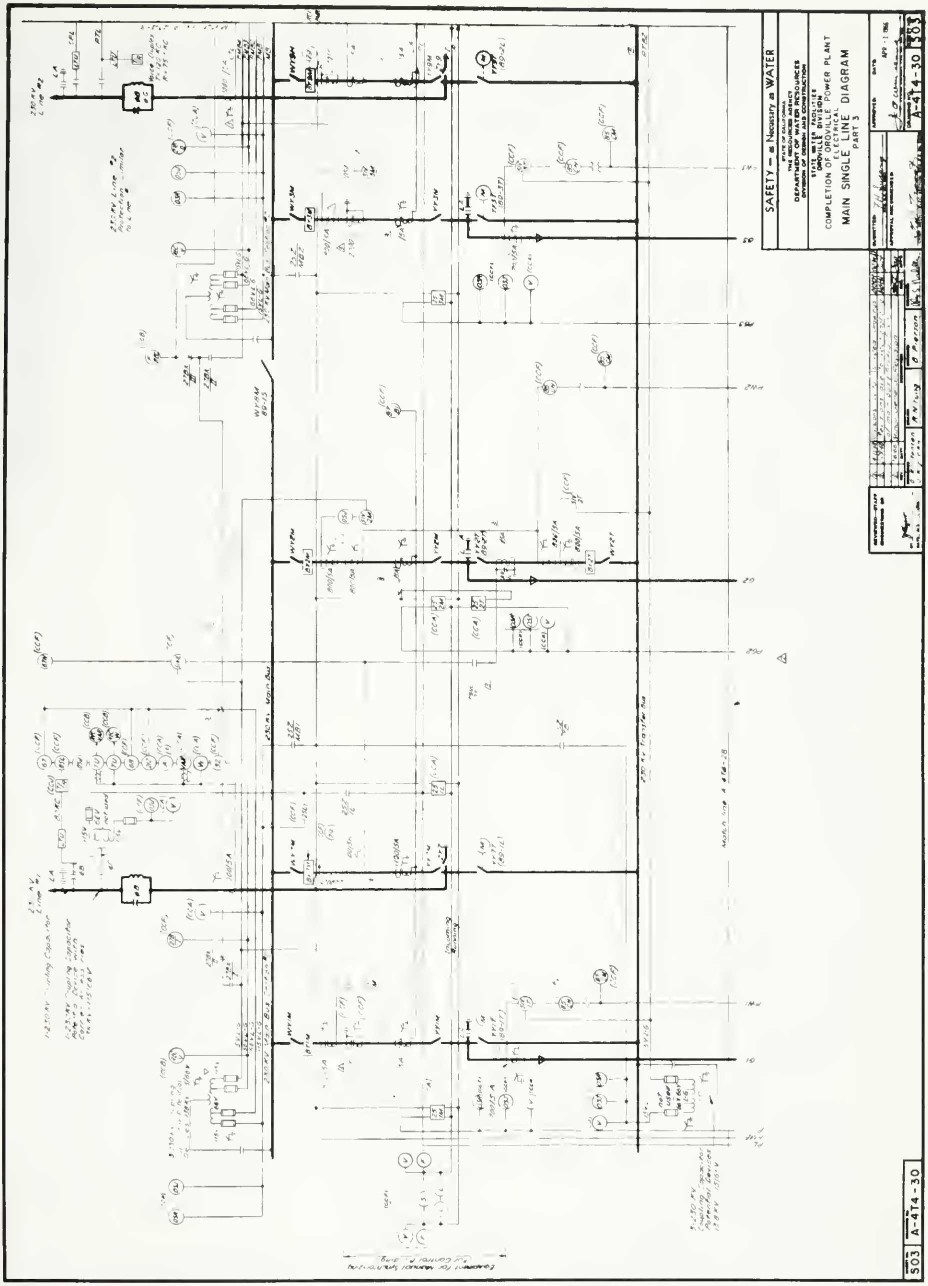

Figure 161. Single-Line Diagram—Part 3

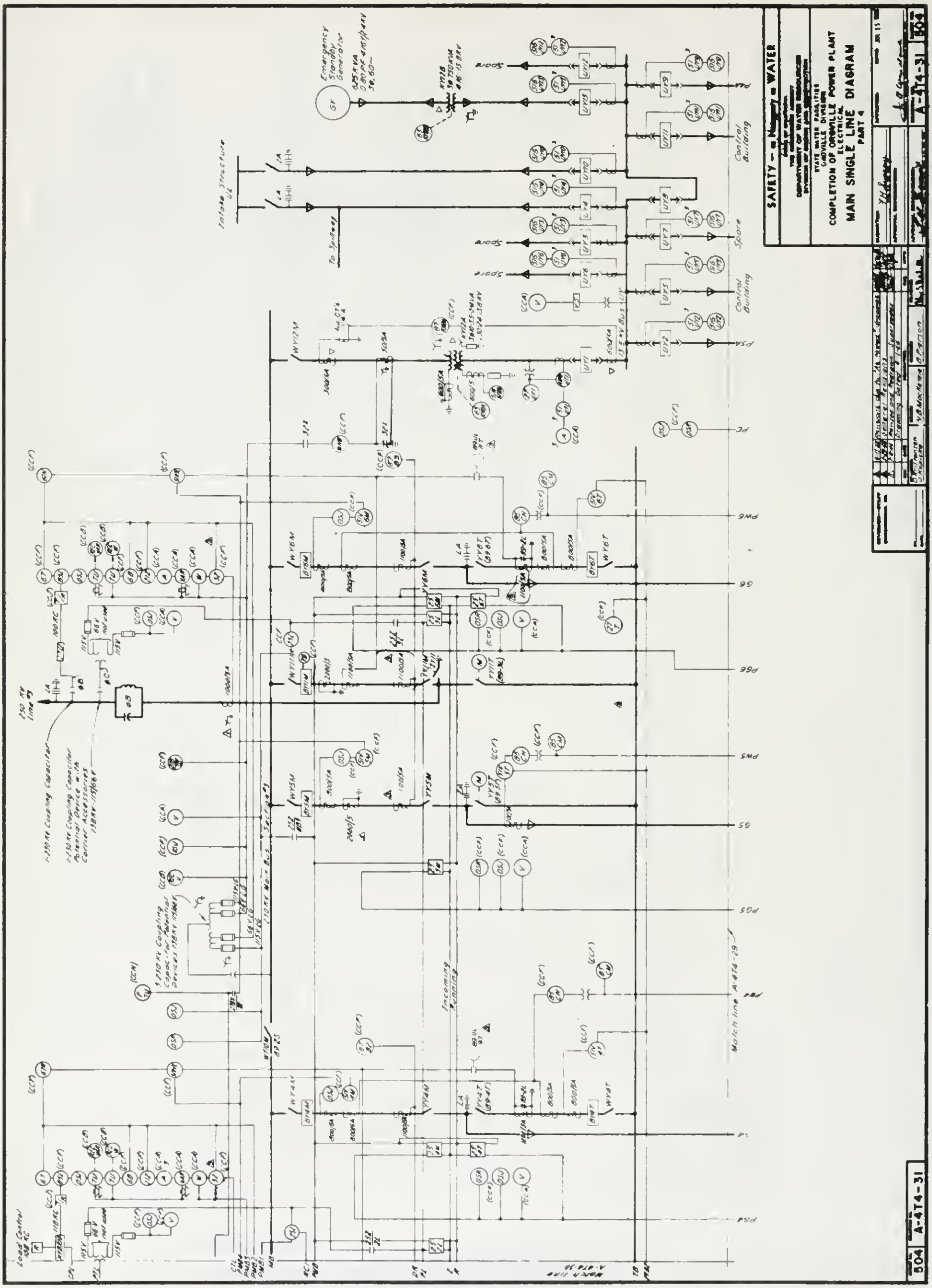

Figure 162. Single-Line Diagram—Part 4

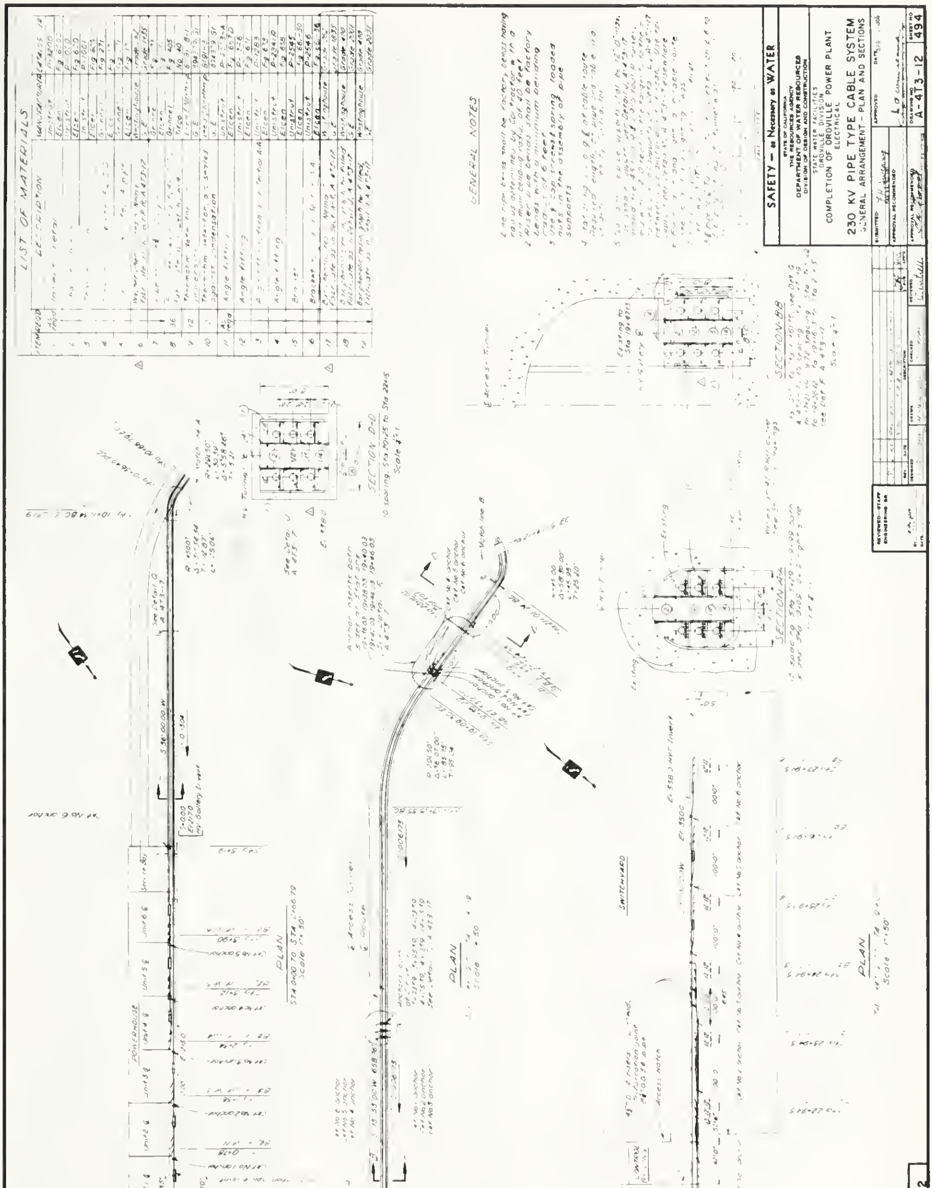

Figure 163. 230-kV Pipe Cable—General Arrangement

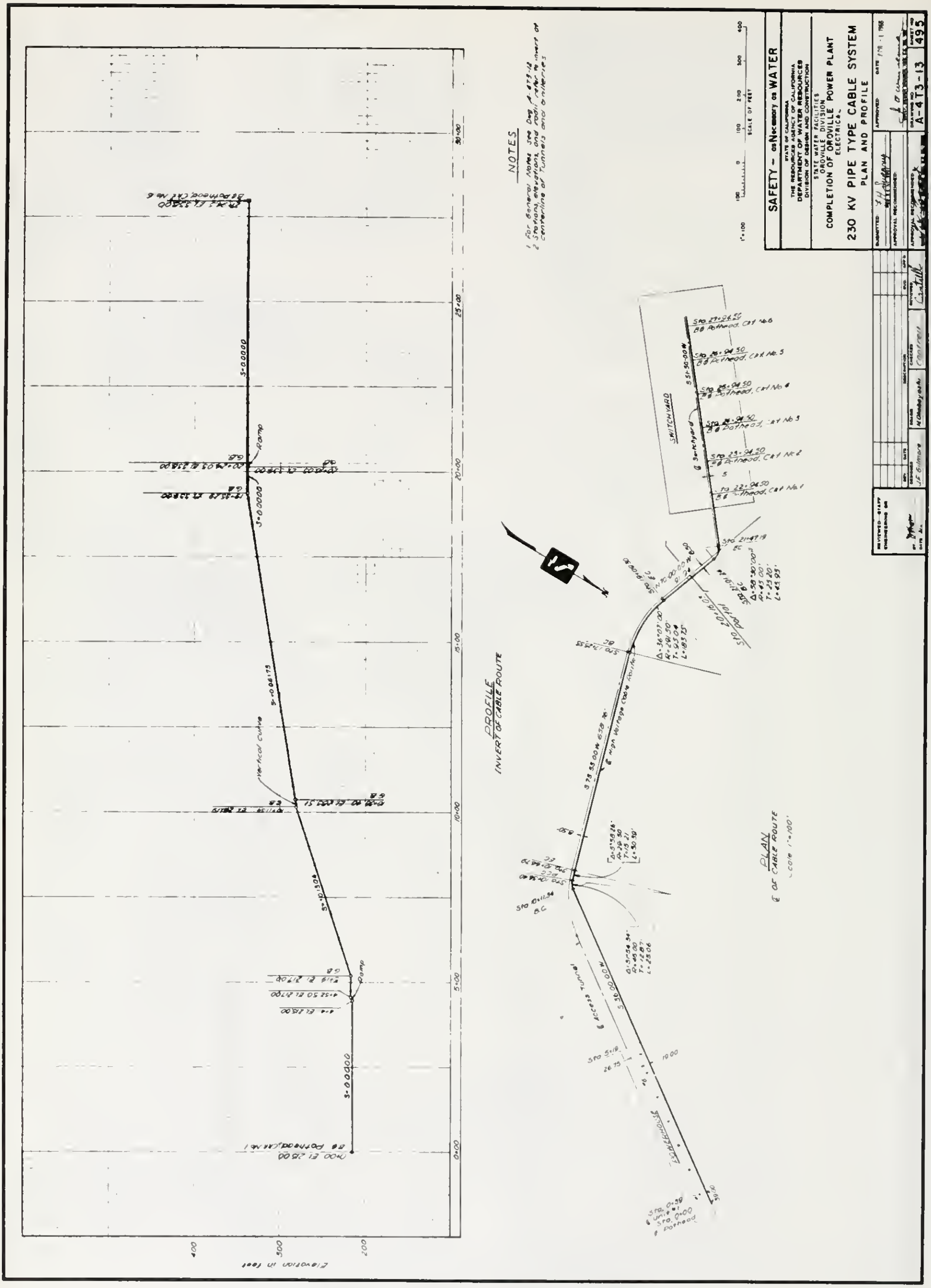

Figure 164. 230-kV Pipe Cable—Plan and Profile

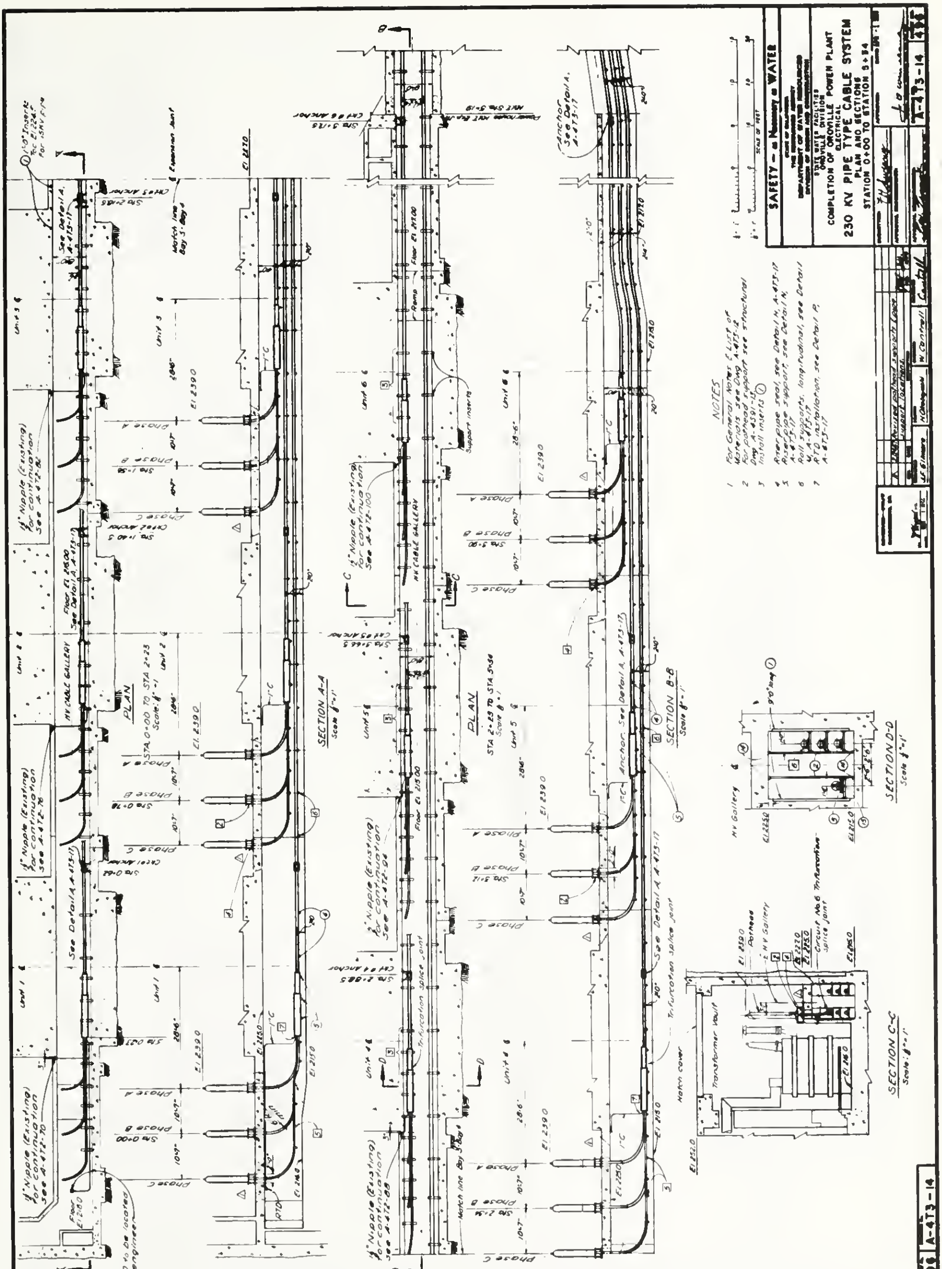

Figure 165. 230-kV Pipe Cable—Plan and Sections

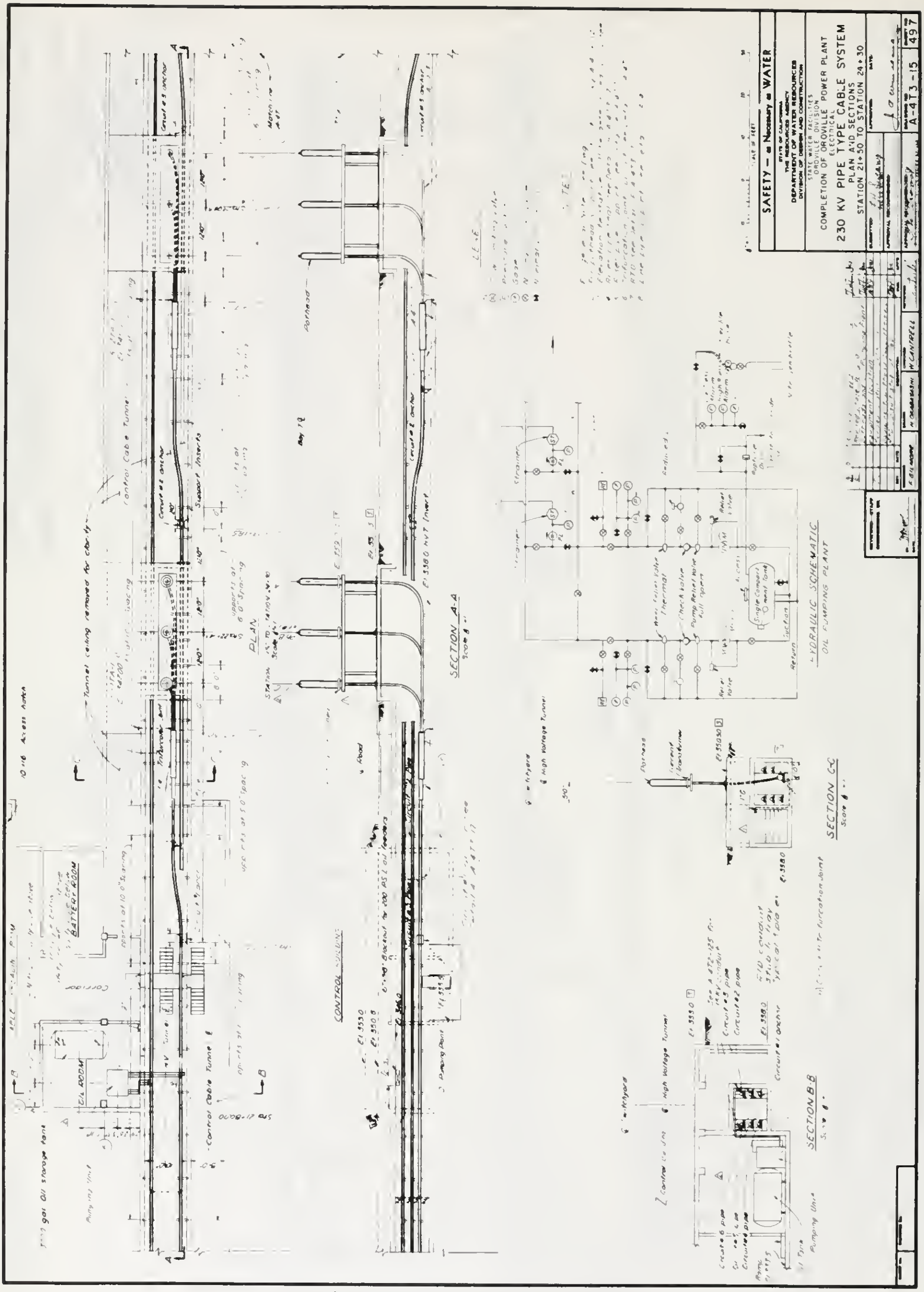

Figure 166. 230-kV Pipe Cable—Plan and Sections—Different Location

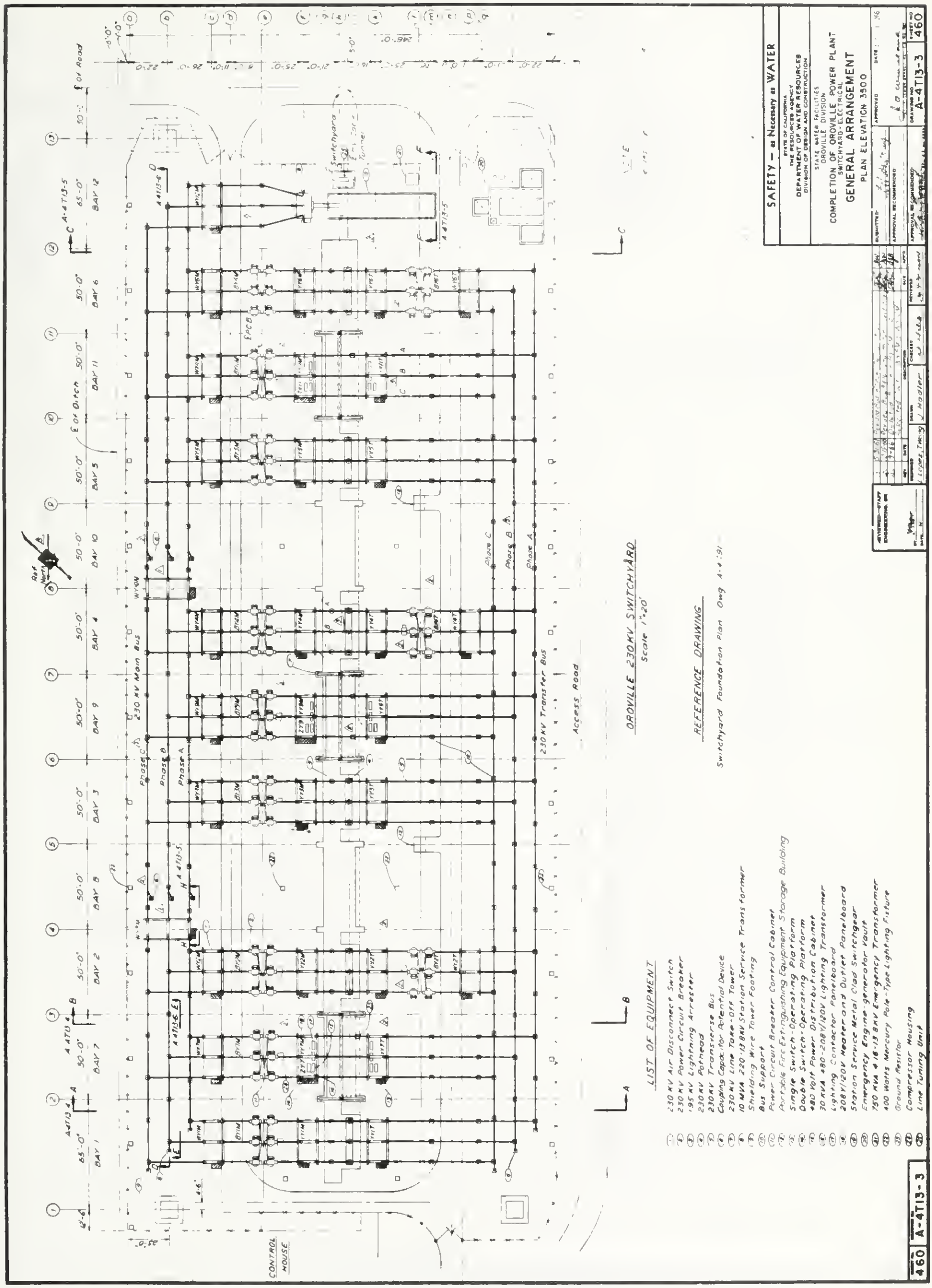

Figure 167. Switchyard—General Arrangement

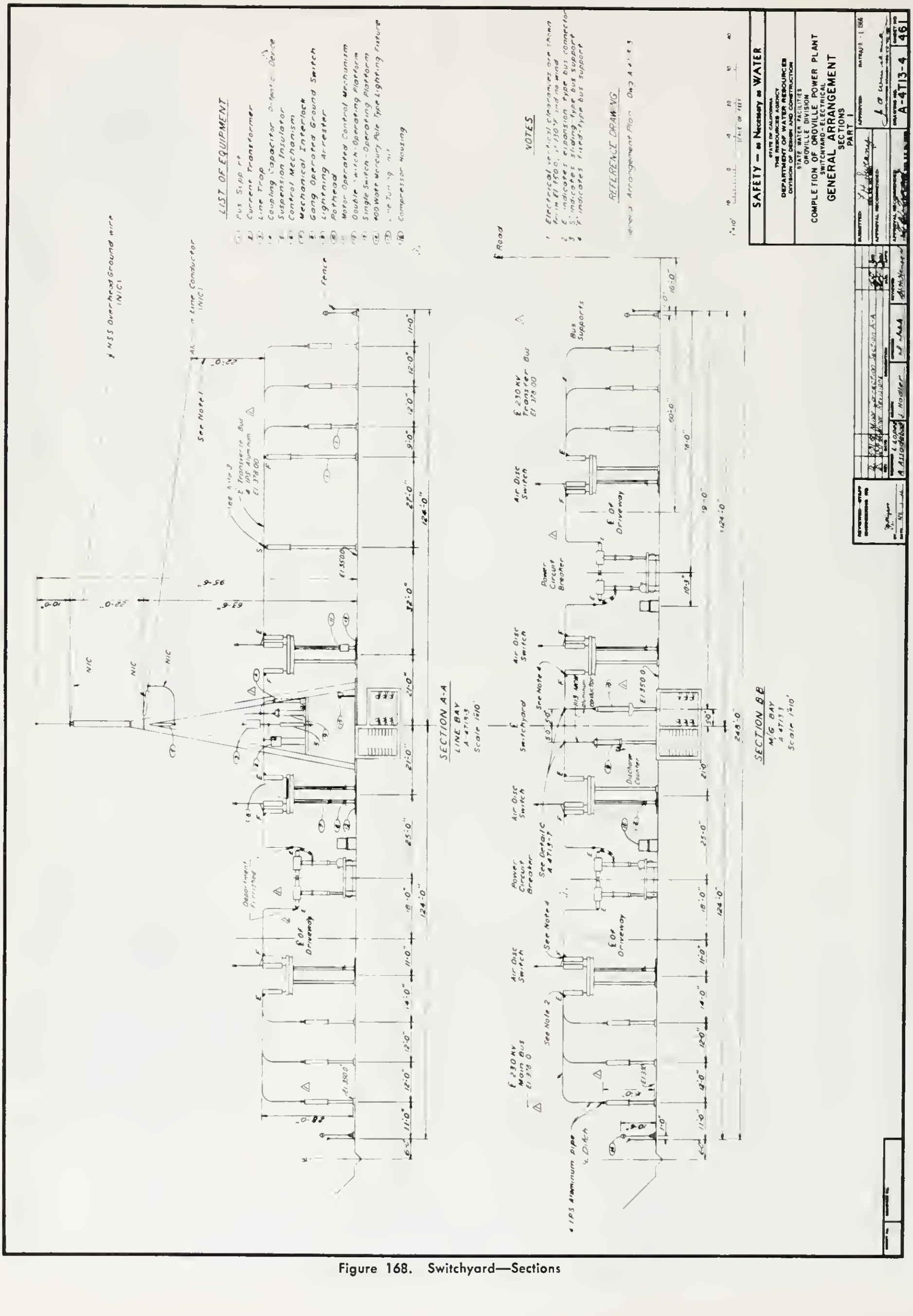

Figure 168. Switchyard—Sections

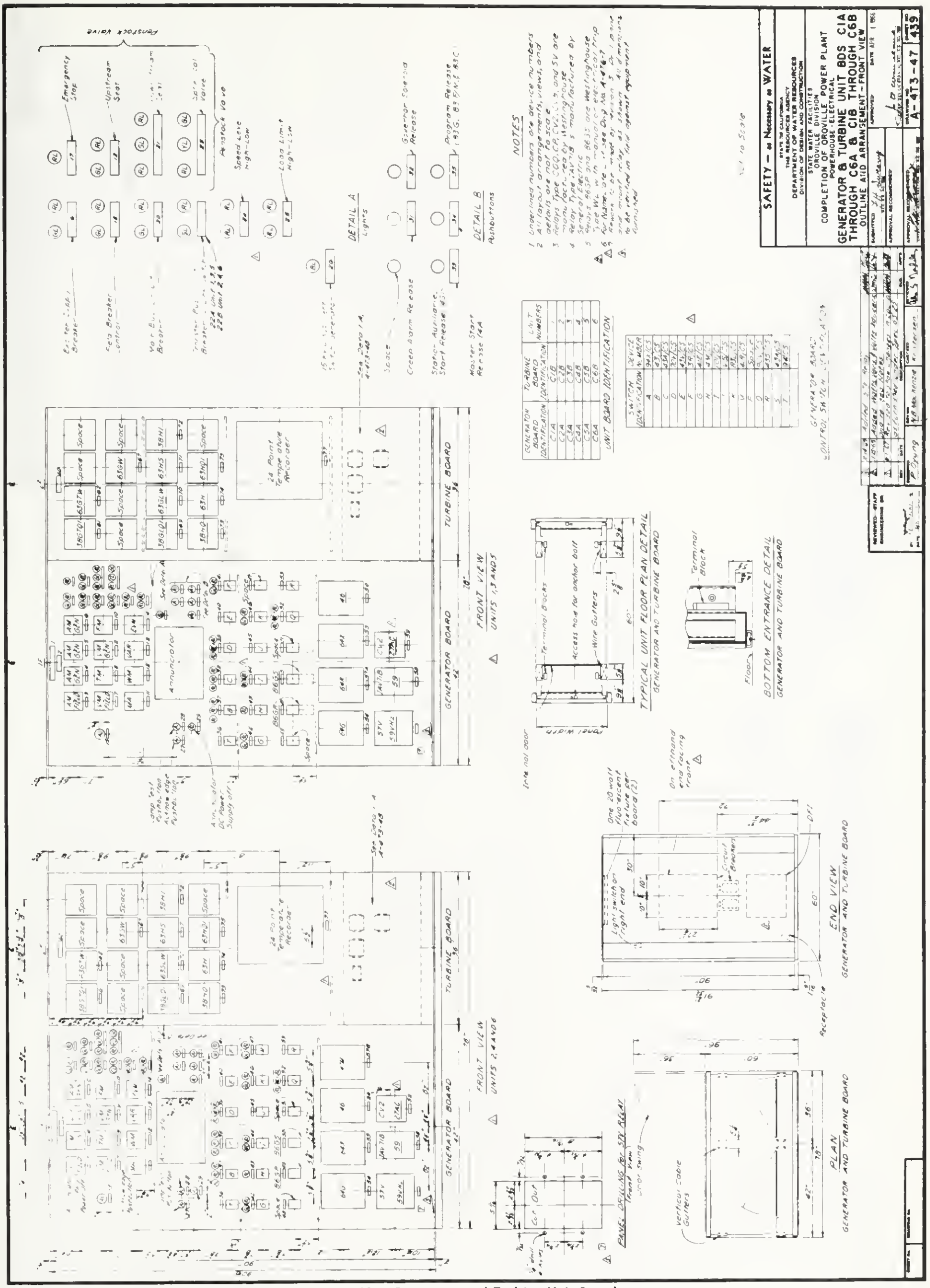

Figure 169. Generator and Turbine Unit Boards

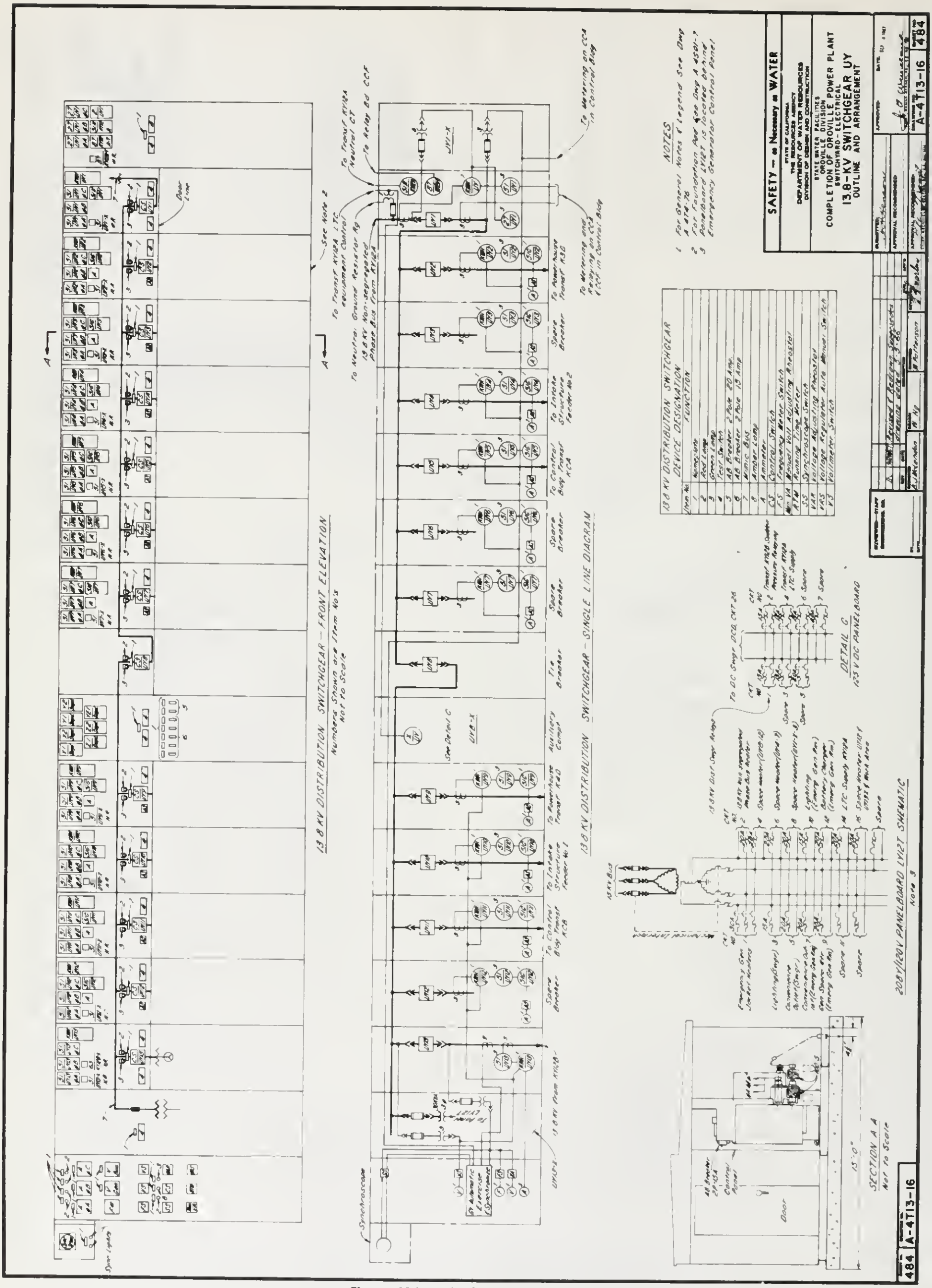

Figure 170. 13.8-kV Switchgear

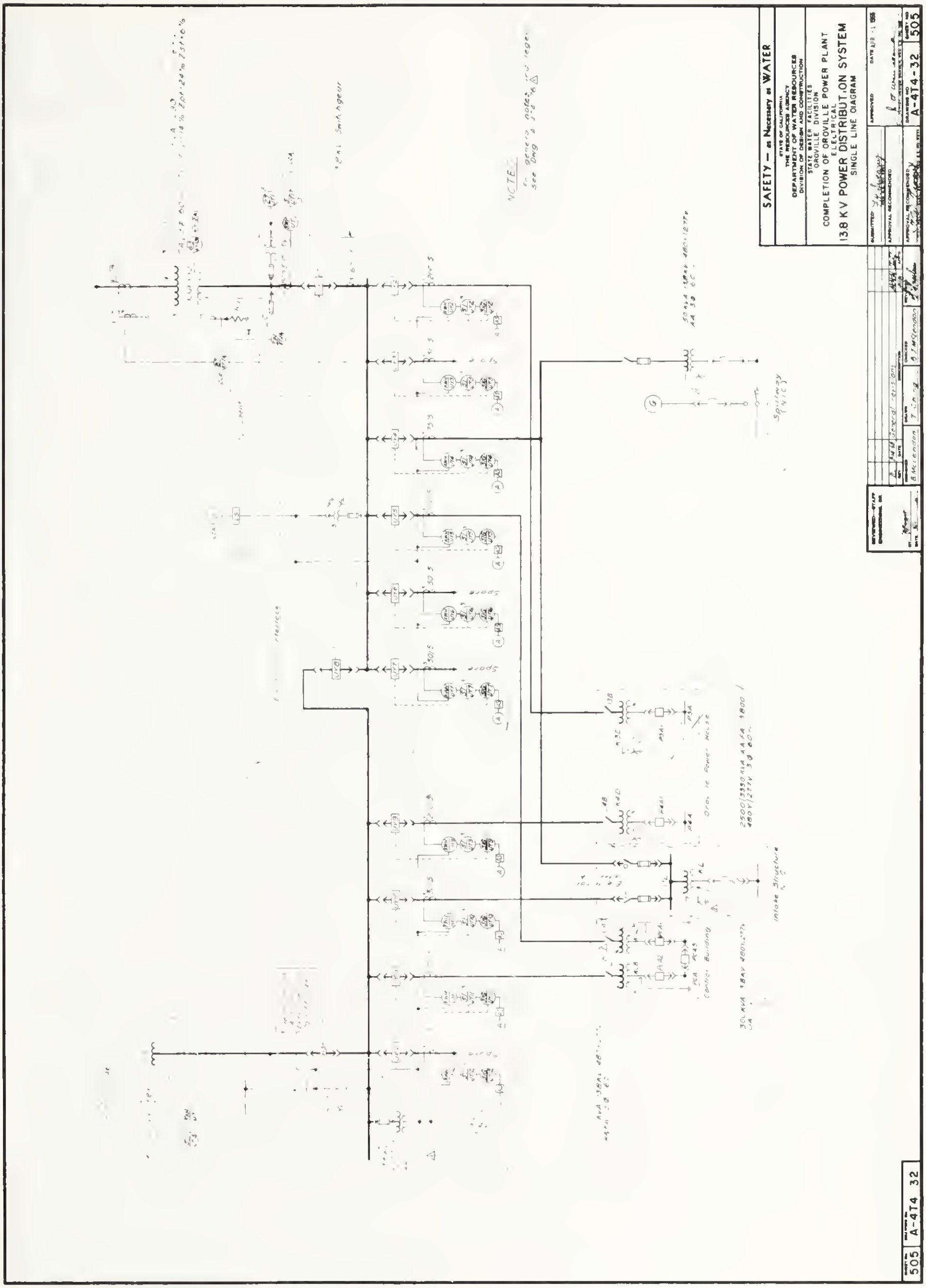

Figure 171. 13.8-kV Distribution System—Single-Line Diagram

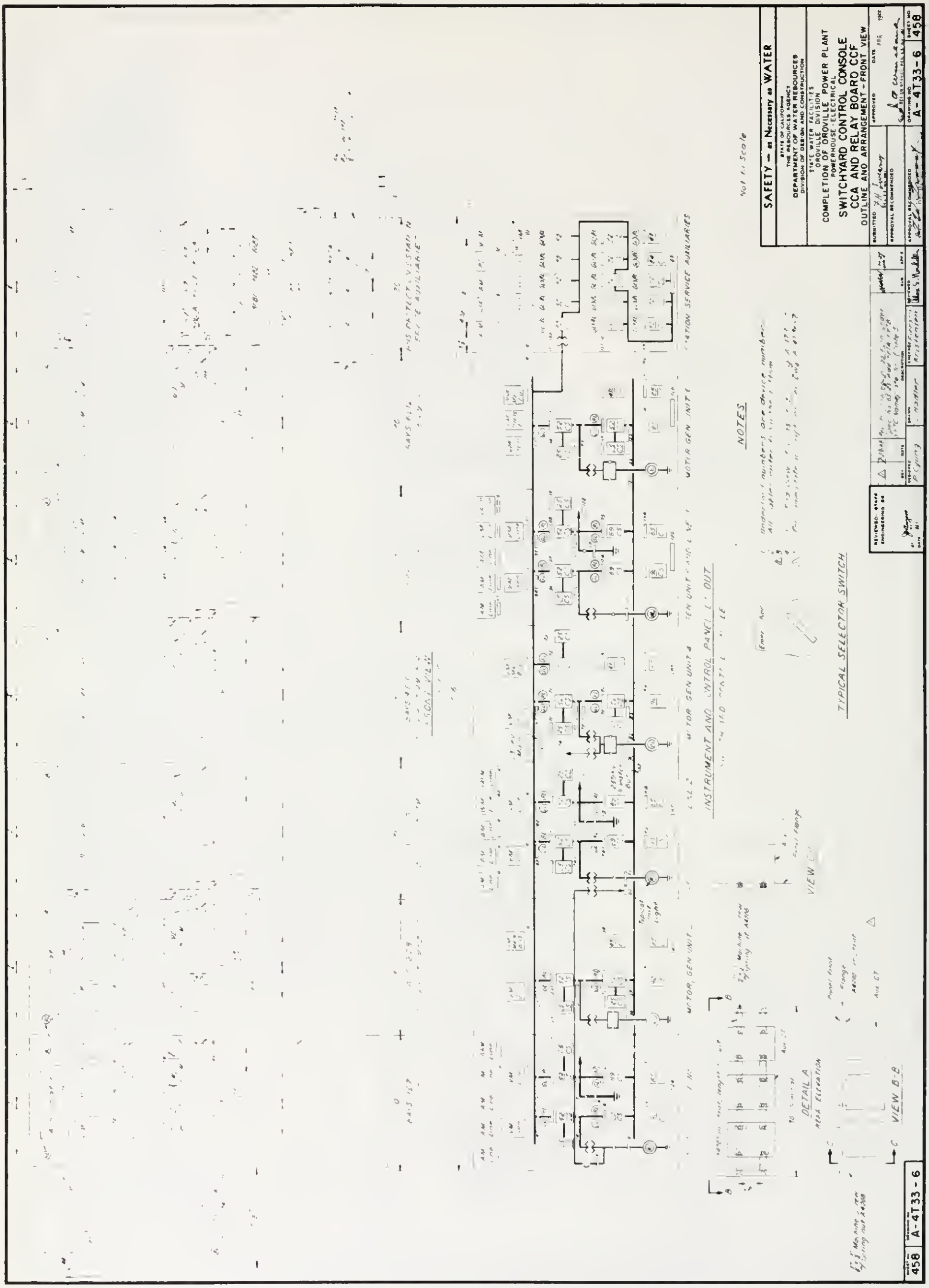

Figure 172. Switchyard Control Console and Relay Board

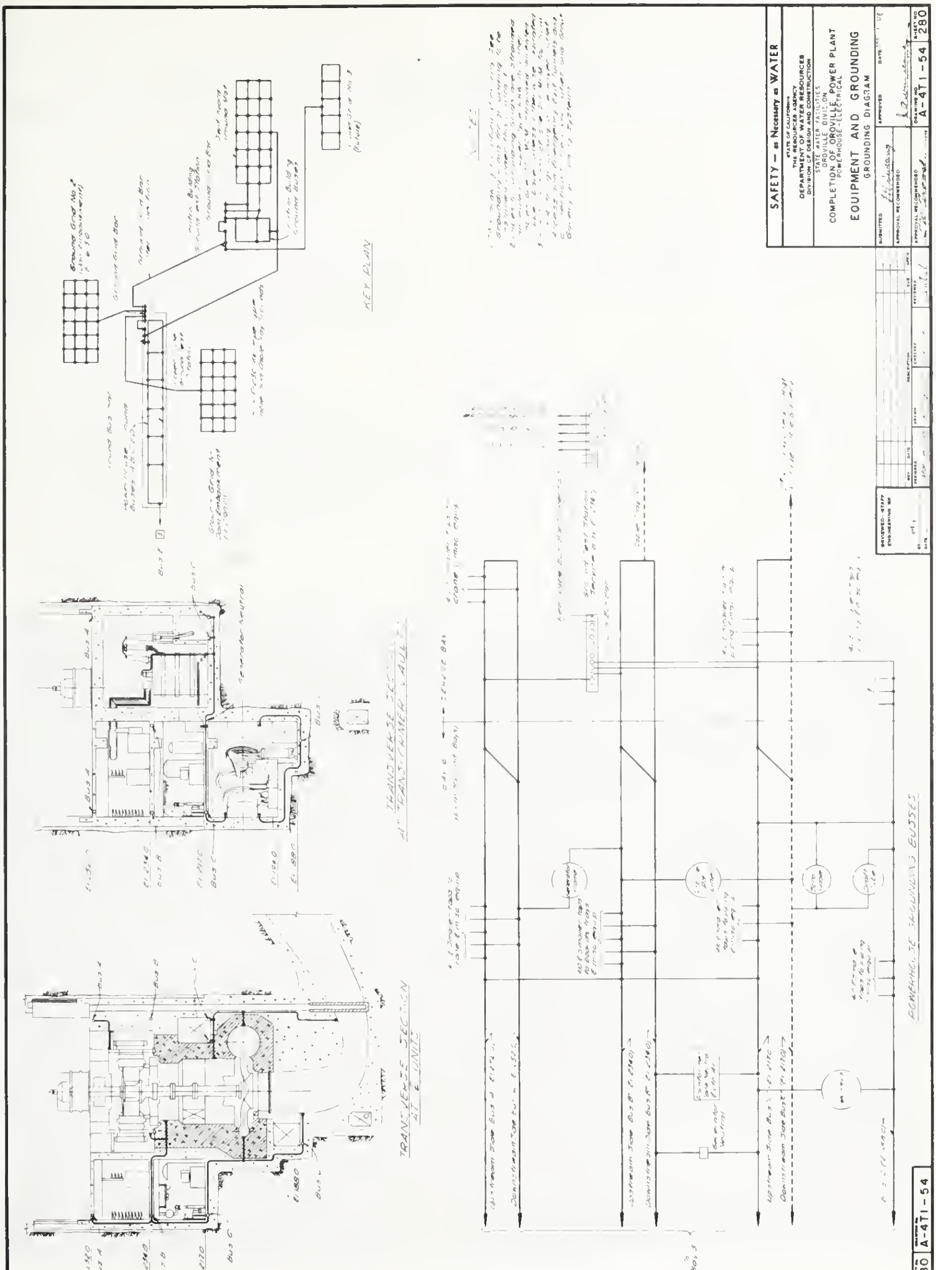

Figure 173. Grounding Diagram

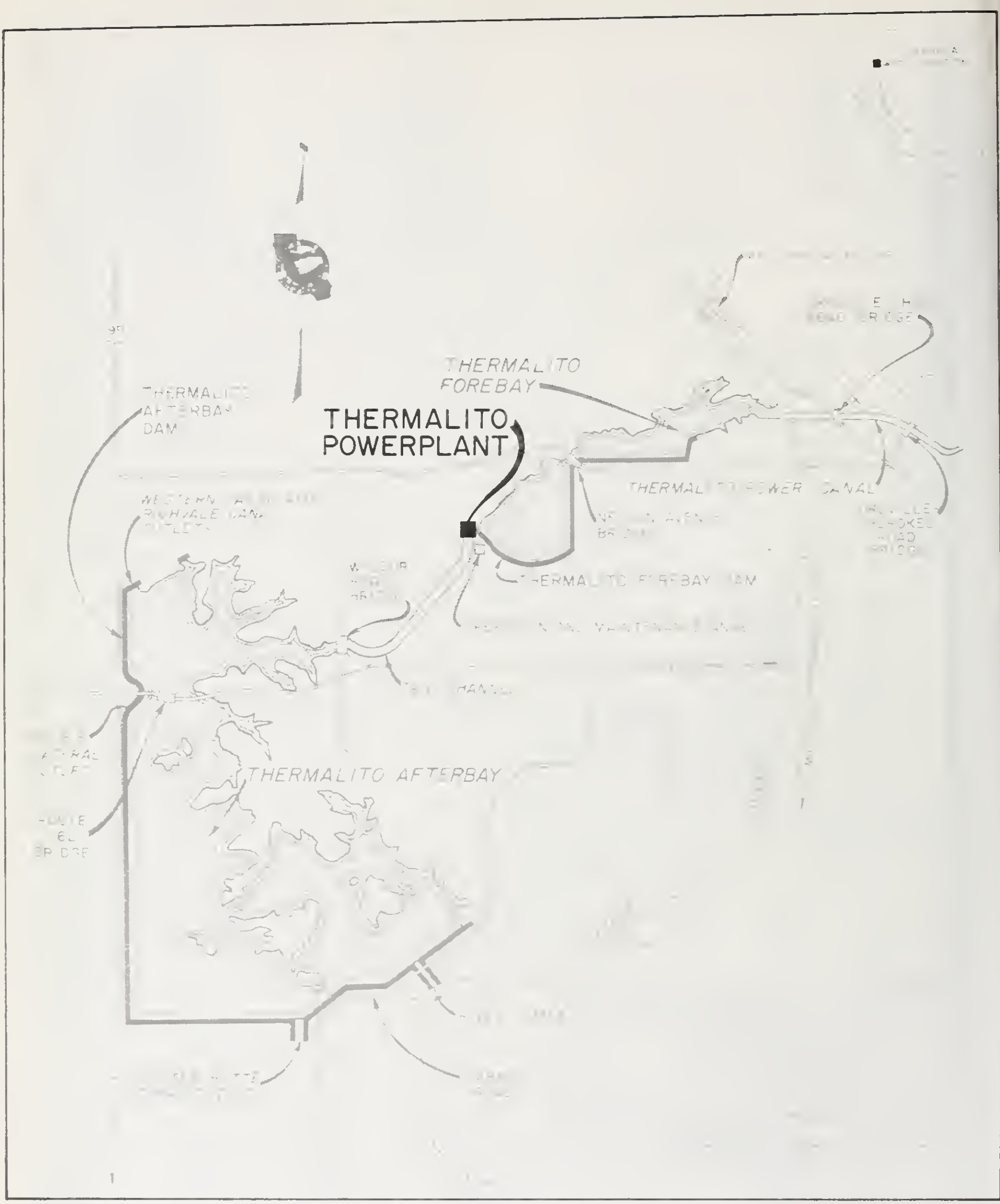

Figure 174. Location Map—Thermalito Powerplant

CHAPTER III. THERMALITO POWERPLANT

General

Location

Thermalito Powerplant is located approximately 4 miles west of the City of Oroville, Butte County. Access to the Powerplant is by a road connecting to Tres Vias Road, an extension of Grand Avenue which leads from Oroville.

Purpose

The Powerplant is a principal feature of the Hyatt-Thermalito pumped-storage power complex. Principal features of the power complex are Lake Oroville and Oroville Dam, Edward Hyatt Powerplant, Thermalito Diversion Dam, Thermalito Power Canal, Thermalito Forebay, Thermalito Powerplant, and Thermalito Afterbay (Figure 174).

Thermalito Powerplant is a pumping-generating plant consisting of three vertical-shaft Francis-type pump/turbines and one vertical-shaft Kaplan-type turbine, with a total power output of 119.6 megawatts (MW).

The plant is operated in tandem with Edward Hyatt Powerplant to produce 725 MW of dependable capacity. Water releases for power in excess of local and downstream requirements are conserved by pump back during off-peak hours through both powerplants into Lake Oroville to be subsequently released for power generation during periods of peak power demand.

The Powerplant was constructed during the period 1964–1969 and began operation in 1968 (Figure 175).

Figure 175. Aerial View—Thermalito Powerplant

Description

Thermalito Powerplant is an indoor type with an in-line arrangement of units. Four unit bays house three reversible pumping-generating units and one generating unit. A fifth bay, located at the easterly end of the plant, houses a bypass structure and a service bay (Figure 176).

Immediately upstream of the plant is a massive, reinforced-concrete, headworks structure with penstocks, penstock intakes, and bypass. At the easterly end of the headworks, the structure abuts the approach channel wingwall which is an integral portion of the forebay dam. On the westerly end, the headworks abuts the approach channel dam.

The entire substructure of the Powerplant and headworks is 351 feet - 6 inches long and 302 feet - 1 inch wide. The steel-frame superstructure is the same length and 64 feet wide. Height of the plant from the centerline of the distributor to the top of the generator floor is 44 feet and from the top of the generator floor to the top of the steel frame is 44 feet. The following tabulation contains pertinent data for the Powerplant.

Representative drawings are included at the end of this chapter.

Water Surface

Thermalito Forebay	
High Water Surface	Elevation 226.0 feet
Low Water Surface	Elevation 222.0 feet
Thermalito Afterbay	
High Water Surface	Elevation 136.5 feet
Low Water Surface	Elevation 123.0 feet

Architectural Design

Thermalito Powerplant conforms to the State Water Project architectural motif. This plant was designed prior to the legislative adoption of Title 24, "Building Standards" and, therefore, its architectural design was based upon other criteria. Additional architectural criteria are given in Chapter I of this volume and in Volume VI of this bulletin.

Geology

Areal Geology

The geologic setting of the area consists of a series of basalt flows partially overlain by continental sediments of the Red Bluff formation and underlain at depth by stiff clays and clean sands of the Ione formation. The basalt flows, which form the Campbell Hills, are made up of three separate members designated Lower, Middle, and Upper. Two interflow layers of volcanic sediments, including basalt rubble, separate the basalt flows. The Lower Interflow between the Lower and Middle Basalt Flows, is widespread throughout the powerplant excavation. The Upper Interflow was encountered only in the area of the approach channel dam. Basalt rubble overlies the basalt flows in scattered areas and fills shear zones in the basalt. Moderately compact sediments of the Red Bluff formation overlie both the flows and rubble in a wedge thickening to the southeast (Figure 177).

Figure 176. Generator Floor

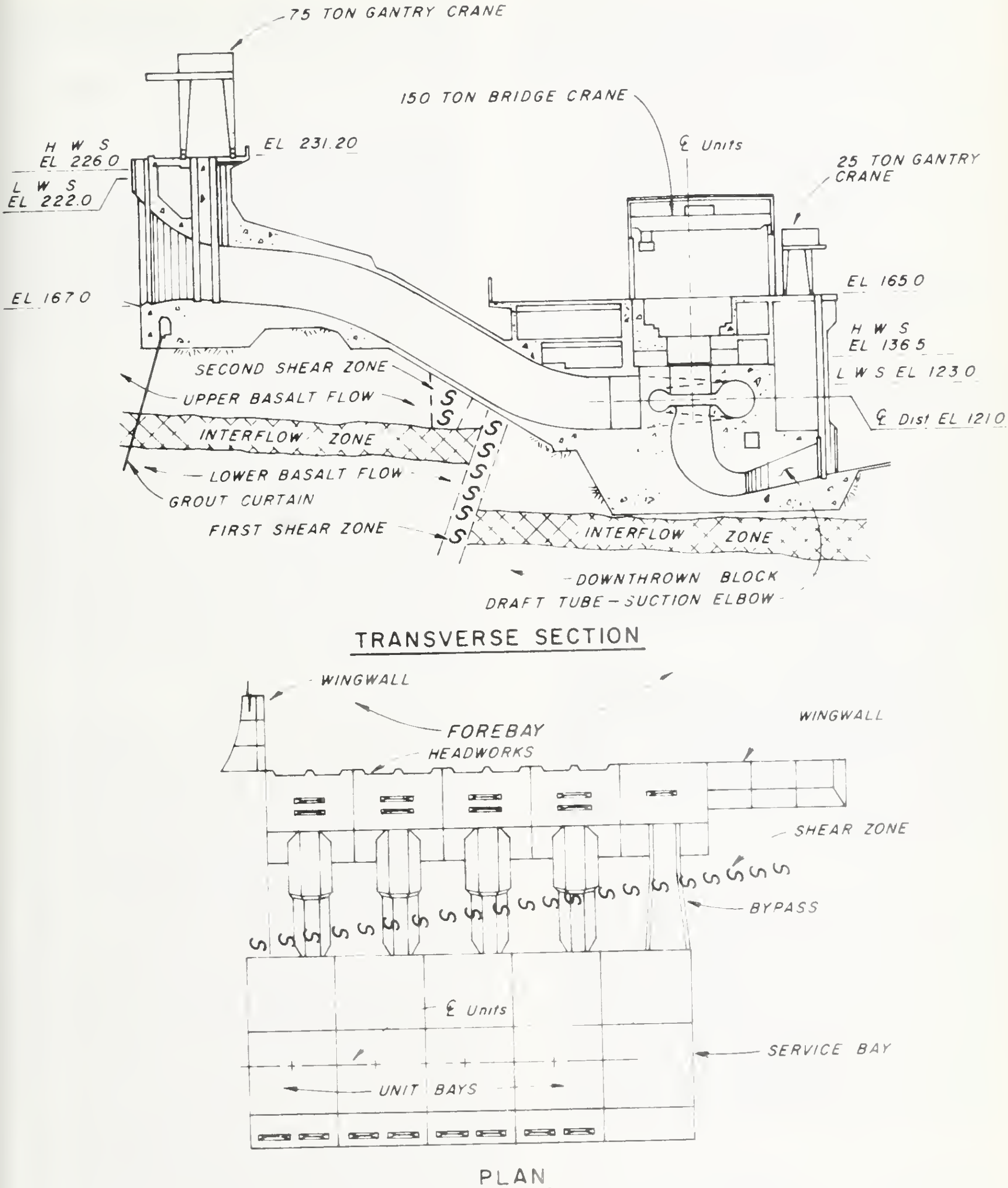

Figure 177. Geology at Thermalito Powerplant

Site Geology

The basalt flows are transected at about 20-foot intervals by nearly vertical regional joints which strike northeast. Joints exposed in the foundation are completely filled with clay and amorphous silica. Water tests conducted during grouting indicated that they are tight.

Design exploration disclosed a major shear zone crossing the site parallel to regional jointing and dipping 74 degrees northwest. Location of the Powerplant was designed to avoid this shear zone and to found the plant on basalt with minimum rock excavation. Final design placed the plant on the downthrown side of the shear with articulated penstocks bridging the shear to an intake structure on the upthrown side (Figure 177). During excavation, however, a second shear zone was encountered lying about parallel to, and 40 to 60 feet northwest of, the first shear zone. Removal of unstable rubble between the two shears left the toe of the planned intake structure near the edge of a 25-foot-high nearly vertical bluff. To ensure stability, the intake structure and penstocks were redesigned to place the intake 30 feet farther back from the bluff.

Basalt in the foundation is mostly fresh to slightly weathered but includes some moderately weathered rock in areas of intense fracturing. The Lower Interflow in most areas is basalt breccia in a matrix of amorphous material. In some exposures, however, it consists of soft cemented sand or dense silt and clay.

Geologic Exploration

Design exploration for Thermalito Powerplant was done from April to October 1960 and from January 1963 to March 1964. During these periods, the design location of the plant was moved several times as subsurface geologic conditions became better known. Interpretation of the complex geology required geophysical exploration, core drilling, and construction of a peg model.

Instrumentation

To monitor the forces acting on and within the headworks structure, Intake Block No. 3 and the bypass block of the headworks were instrumented. These instruments consist of uplift cells to determine uplift pressure along the contact plane between the concrete and rock, soil stress meters along the contact plane of concrete and soil, and stress and strain meters to monitor any changes in concrete stress near the foundation and at critical points within the structure. These meters also are used to measure temperature changes within the structures to accurately estimate the effects of thermal stresses within the more massive portions of the blocks.

Seismicity

The Powerplant is in an area that is considered seismically active but generally not considered susceptible to major earthquakes. All elements of the plant, including the structure and critical mechanical and electrical equipment, were designed to withstand moderate earthquake forces (i.e., 0.1g).

Civil Features

Preliminary Studies

Preliminary design of Thermalito Powerplant was closely coordinated with studies of Edward Hyatt Powerplant since the two plants were to operate in tandem. Unit selection was influenced to a large degree by Edward Hyatt Powerplant operation and the location of an afterbay of adequate capacity to permit pump-storage operation. Final siting was influenced further by the geology of the area. Preliminary design consequently involved only the study of alternative schemes for the structure.

During the course of the studies, four schemes were conceived and investigated for feasibility and economy. Scheme No. 1 consisted of the powerhouse separated from the intake structure and connected by long reinforced-concrete penstocks. Scheme No. 2 was a close-coupled arrangement of the powerhouse and intake structure with the penstock as an integral part of the structure. Scheme No. 3 was a monolithic structure incorporating the intake with the powerhouse, making the shortest possible structure. Scheme No. 4 was similar to Scheme No. 1 except that the penstocks were shortened for increased economy (Figure 177). This last scheme was adopted as being the most economical and suitable to the geologic conditions.

Site Development and Drainage

The plant is situated on the side of a hill and did not require major bowl excavation for its construction. This site was best from the standpoint of the geology as mentioned earlier and readily accommodated the forebay and afterbay configurations. The headworks of the plant is located at the westerly end of the forebay dam and forms an integral portion of it.

The major elements of site development for the plant consisted of access roads, parking area, sewage disposal facilities, potable water supply, and site drainage.

A paved road was constructed to provide access to the site from Tres Vias Road. Other roads branch from this road and provide access to various areas of the facilities. At the easterly end of the plant, a paved parking and turnaround area was provided for vehicular traffic.

Sewage facilities consist of a septic tank and two seepage pits located southeast of the plant. Raw sewage is ejected by air from tanks in the plant to the septic tank, where it undergoes treatment process. Effluent from the septic tank discharges into the seepage pits. Potable water is obtained from a fresh water well located near the entrance to the site.

Site drainage is a minor concern at this plant with only local drainage being collected and routed around the area. Most runoff from the hillside behind the plant either discharges into the forebay or is diverted to the west by natural channels. The runoff that drains toward the plant from natural and cut slopes is collected in ditches at the bottom of the slopes and drained to the tailrace channel through culverts.

To relieve potential uplift pressures under the intake structure, drain holes were drilled from the grout gallery and angled downstream from the grout curtain. Holes were drilled passing through the pervious zone adjacent to the Lower Interflow material and approximately 5 feet into hard rock of the Lower Basalt Flow. Drainage from these holes is collected in a trench in the headworks inspection gallery and discharged into the bypass.

Powerhouse Layout and Design

The plant consists of the headworks structure, four penstocks, bypass structure, powerhouse structure, four generating units, and plant equipment.

As previously mentioned, this plant is operated on essentially the same schedule as Edward Hyatt Powerplant. The normal operating flow for generation is 13,500 cubic feet per second (cfs) with a maximum of 16,500 cfs. The normal pumping flow is 6,000 cfs with two of the three pump-turbines matching the pumpback capability at Edward Hyatt Powerplant. Motor-driven hoists raise and lower the draft-tube trashracks in order to have them out of the opening during the generation cycle and in place during the pumping cycle. Four steel bulkhead gates for the draft-tube entrances allow dewatering the units and draft tubes for maintenance.

Powerhouse Structure. The substructure of the powerhouse was constructed of reinforced concrete with four unit bays and the bypass-service bay block. The superstructure was constructed of rigid steel frames enclosed with precast concrete panels integrated with a concrete block wall system and a metal roof deck with built-up roofing. The superstructure is structurally independent within each bay.

The switchyard is located between the headworks structure and the powerhouse proper, utilizing a portion of the top deck of the powerhouse substructure. The dead-end towers, takeoff towers, bus-support towers, and disconnect-switch towers were constructed with structural tubing that gives the switchyard a streamlined look. Firewalls, constructed of 8-inch reinforced-hollow-concrete block, separate the transformers and, in addition, support the switchgear.

Under normal operating conditions, nearly the entire flow from Edward Hyatt Powerplant passes through Thermalito Powerplant. It is imperative that an emergency shutdown at Thermalito will not necessitate a shutdown of Hyatt. To prevent such a shutdown, a bypass structure was built to pass a maximum of 10,000 cfs of the flow from Edward Hyatt Powerplant into Thermalito Afterbay. This bypass was also designed to pass controlled releases up to 3,200 cfs for local and downstream use when Thermalito Powerplant is shut down. The flow from the bypass goes underneath the service bay structure, which was constructed utilizing the bypass walls as support.

A unique feature of the powerhouse design is the provision for adding future units. To accommodate a future addition, the west end of the structure was provided with shear keys, embedded water stops, and knockout panels. This future extension will be in a westerly direction, with the number of units to be determined by matching the flow requirements of additional units at Oroville Dam.

Design Considerations. Design and location of the plant were determined by the overall stability requirements of the powerhouse and headworks structures, economy in concrete and excavation quantities, penstock lengths, and hydraulic efficiency.

Plant dimensions were held to a minimum taking into consideration water passages, unit size, auxiliary equipment, and minimum safe structural member sizes.

Safety of the plant structure and the forebay dam was considered in the evaluation of the plant location in relationship to the dam. Factors such as head and tailwater surfaces, foundation conditions, dam type and stability, and tailrace channel slopes were the critical items in the safety analysis.

All structural elements were designed to withstand expected forces which include dead and live loads, lateral loads, hydrostatic pressure, equipment loadings, and other special loadings.

Foundation Design Considerations. Because of its massive weight, the structure required a sound foundation. Consequently, the powerhouse was founded on the Middle Basalt Flow and the Lower Interflow on the downthrown side of the shear zone. The penstocks and bypass were founded on the Middle Basalt formation and bridge two shear zones between the plant and the headworks. To accommodate any possible differential settlement, the penstocks connecting the powerhouse and headworks structure are articulated at both ends.

During design, it was determined that the Middle Basalt was adequate for the foundation, but there was some doubt with regard to the structural adequacy of the Lower Interflow material. The necessity for excavation of this material and its replacement by backfill concrete were studied and, as a result, this decision was deferred until excavation reached elevation 72 feet. After studying the results of plate bearing tests as well as inspection of the foundation surface, core boring samples, and an exploration trench, the foundation at elevation 72 feet was determined to be satisfactory.

Headworks Structure Layout and Design

General. The headworks is a reinforced-concrete gravity structure consisting of four 70-foot-wide blocks that serve as intakes for the four penstocks. A fifth 70-foot-wide block serves as a part of the bypass facilities.

Each intake is formed by a transition within the length of the structure from a double rectangular section to a circular section matching the size of the penstocks. Each intake is equipped with trashracks and provisions for gates and stoplogs. Two fixed-wheel gates and a bulkhead gate were provided for closing off three units at a time.

Vehicular access to the top of the headworks is along the crest of the forebay dam, and personnel access to the powerhouse is available by means of a catwalk and stairway on the bypass block. A 75-ton gantry crane serves the top deck of the structure and operates the gates and trashracks.

Model Studies. An experimental study of the hydraulic performance of the Thermalito Powerplant intake was made at the Hydraulic Laboratories of the Department of Water Science and Engineering of the University of California, Davis. Due to geologic conditions, the approach channel was designed parallel to the headworks, resulting in a 90-degree flow angle change before entering the penstock intakes.

Although the plant was designed for reversible operation, only the study of generation flow patterns was deemed necessary. Tests on a 1:30 scale model were conducted primarily to determine hydraulic performance of the approach channel, penstock and bypass intakes, bypass spillway and roller bucket, and tailrace.

Flow conditions in the approach area to the penstocks for the initial design configuration were unsatisfactory at high flows. Of particular significance was the circulation immediately in front of the penstock intakes which established transverse currents parallel to the headworks. These currents were partially responsible for the development of vortices which formed over the penstock entrances causing entrained air to enter the penstocks. A permanent large vortex, fully aerated, formed at the entrance to the bypass spillway when it was in operation.

No single factor was solely responsible for the vortices. Apparently the geometry of both the approach channel and forebay areas and the intakes contributed to their formation.

In order to eliminate the vortices, tests were conducted to improve several design features. These tests led to the following design modifications:

1. Widening the approach channel.
2. Raising the invert of the forebay in front of the plant.
3. Altering the headworks from sloping to vertical.
4. Increasing the upward flaring of the intakes.
5. Attaching a continuous vertical skirt to the piers which protrude below the water surface.
6. Replacing the vertical retaining wall at the left abutment with an inclined gravity wall.

Other trial modifications of the original design were tested but were discarded for various reasons. The results of all the testing are discussed in a publication entitled "Hydraulic Investigations of the Thermalito Power Plant", by the Department of Water Science and Engineering at the University of California, Davis.

Design Considerations. With the headworks so closely tied to the powerhouse, sizing, economy, location, and safety considerations were considered in conjunction with plant design. Structural design involved analysis of all the forces acting on the structure and the hydraulic criteria of the intakes.

Because the headworks is a portion of the forebay dam, a thorough stability analysis was conducted for the structure. Two conditions, static loadings and static plus dynamic loadings, were investigated to check against overturning, sliding, flotation, and foundation pressures, and the structure was determined safe.

Provisions for possible expansion at the westerly end of the plant were also included in this structure.

Foundation. The headworks is founded on the Middle Basalt formation, which has adequate strength to carry the heavy load of the structure.

Approach Channel Wingwall. A concrete gravity wingwall, 100 feet long and about 50 feet high, serves as a transition between the powerhouse headworks and the earthfill forebay dam. This structure was designed to match the architectural motif of the headworks, providing continuity of the structure's lines into the dam.

Approach Channel Dam. This small dam is a concrete gravity structure about 230 feet long and tapering in depth from 2 feet to a maximum of 82 feet. It serves to close the end of the approach channel and extends from the headworks to the hillside behind the plant. The structure also was designed to match the architectural motif of the headworks, thus providing continuity of the structure's lines into the hillside. The drainage gallery of the headworks extends into the structure to provide access to the foundation pressure relief drains.

Approach Channel. Water is conveyed from Thermalito Forebay to the plant through the approach channel. This channel is enclosed by a portion of the forebay dam, the approach channel wingwall, the headworks structure, the approach channel dam, and the hillside north of the plant. As discussed earlier, this channel was model-tested along with the plant to determine the best hydraulic configuration, with the result that the aforementioned modifications were made in the design.

Penstocks. Four penstocks, one for each unit, deliver water from the approach channel to the units. The maximum penstock diameter for the Kaplan turbine is 24 feet, and the maximum diameters for the three pump-turbines are 21 feet. Each penstock is a steel-lined reinforced-concrete structure joined to the headworks with an expansion joint and with an articulated section to the powerhouse to allow rotation in the event of settlement of either main structure.

Bypass. The bypass is an integral part of the powerplant structure. It is a submerged single-gated sluice consisting of a rectangular entrance with elliptical entrance curves, a radial gate, and a steep diverging chute terminating with a slotted, roller-bucket, energy dissipator. The bypass was designed to pass a maximum flow of 10,000 cfs without sweepout of the hydraulic jump occurring in the tailrace channel. Additionally, the bypass was designed to pass a controlled flow of 3,200 cfs for downstream use in case of a powerplant outage. This portion of the structure also was model-tested and found to fulfill the design requirements.

Trashracks. Because this is a pump-generating plant, steel trashracks were provided for each unit for both the penstock intake and the draft-tube entrance. The trashracks were assembled in panels with vertical bars spaced to provide 5½-inch clearance between them. Provisions have been made to install trash rakes for mechanical cleaning if the need develops. Trashracks for the headworks were placed in a separate designated trashrack slot, while the draft-tube trashracks were placed in a slot designed to accommodate either the racks or the bulkhead gates.

Bulkhead Gates and Stoplogs. Each intake water passage has an upstream stoplog slot and a downstream service gate slot. Two steel fixed-wheel gates and one intake stoplog provide a means of shutting off the penstocks for maintenance.

Mechanical Features

General

The mechanical installation includes three pump-turbines and one turbine, governors, cranes, and auxiliary equipment (Figures 176 and 178).

Chapter 1 of this volume contains information on mechanical equipment and systems for Thermalito Powerplant which are common to other plants in the State Water Project. Information and descriptions which are unique to this plant are included in the following sections.

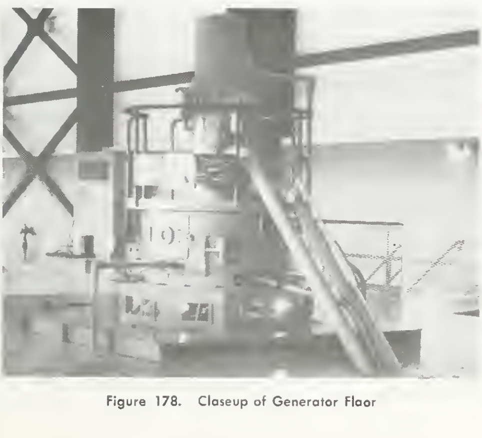

Figure 178. Closeup of Generator Floor

Plant Capacity and Operating Conditions

Since Thermalito Powerplant operates in tandem with Edward Hyatt Powerplant, flows passing through it are in nearly exact relationship with the flows through Hyatt. Based on this criterion, the capacity of the plant adjusts to optimize the dependable capacity of both plants.

Selection of Units

Preliminary design envisioned installation of the largest possible reversible units compatible with the state-of-the-art, manufacturer capabilities, and the existing terrain. This criteria led to selection of three low-head low-speed pump-turbines to fulfill the generation requirements. However, when considering the maximum releases from Hyatt, units of this size and speed required substantial submergence, provided a pumping capability more than double that required, and precluded operation at best efficiency point when responding to fluctuating flows from Hyatt.

To optimize the design, the three pump-turbines were reduced in size to deliver approximately 3,000 cfs each in the pumping mode. Since Edward Hyatt Powerplant pumps a maximum of approximately 6,000 cfs, this provided a spare pump, which was considered prudent in view of the adverse effect a deficiency in pumping at Thermalito would have on simultaneous pump-back operation at Hyatt.

To complement the operation of the pump-turbines, a Kaplan turbine was added to the plant. Introduction of the Kaplan turbine with its excellent efficiency over a wide range of flows permitted operation of the pump-turbines at constant load at best efficiency while changes in flow are passed through the Kaplan turbine. This design refinement increased the overall dependable capacity of the two plants and the efficiency of Thermalito Powerplant by 1½%.

Hydraulic Transients

Since the Powerplant is above ground and each unit is connected to an individual penstock, the transient analysis was relatively simple and routine. Penstocks were designed for a maximum pressure of 60 pounds per square inch (psi), the maximum static head plus a water-hammer pressure rise of 37%. The hydraulic transient criteria were as follows:

1. Kaplan unit rejecting 115% of rated generating capacity at maximum head of 101 feet with a speed rise limited to approximately 45%.
2. Pump-turbine rejecting 115% of rated generating capacity at a maximum head of 101 feet with a governor time of 20 seconds, recommended by the manufacturer, and a resulting speed rise approaching 70%.

3. Power failure while pumping against the maximum head of 102 feet.

Hydraulic Transient Tests. Field tests to verify that the system operated as designed were successfully performed in June 1969, although a problem was encountered while testing a pump-turbine. Unusual penstock pressure transients associated with load rejection and power failure were recorded. Particularly violent surging, accompanied by loud banging or thumping sounds emanating from the turbine pit, occurred during the pumping power failure tests. The transients exceeded design pressure of the penstocks and occurred at approximately 70% speed with the wicket gates essentially closed. Analyis of test records indicated this phenomenon was caused by the unit being sustained at reduced speed by an excessively long servomotor cushioning time. At this reduced speed, resonance occurred with the forcing frequency of the machine and natural frequency of the penstock. The condition was corrected, and the pressure rise reduced, by adjustment of the servomotor cushioning time and minor changes in the governor electrical circuits for the pumping cycle.

After the final adjustment, a 115% load rejection on the Kaplan unit at 94 feet of head produced a total pressure of 52 psi with a speed rise of 41%. The pump-turbine load rejection test resulted in a 56-psi total pressure with an attendant speed rise of 60%; the corresponding test for power failure in the pumping mode resulted in a total pressure of 53 psi.

Equipment Ratings

Turbine		
Manufacturer:	Allis-Chalmers Manufacturing Company	
Type:	Kaplan	
Horsepower:	45,000 @ 85 feet	
Head:	85 to 102 feet	
Speed:	138.5 rpm	
Maximum Efficiency:	93.6%	
Pump-Turbines		
Manufacturer:	Allis-Chalmers Manufacturing Company	
Type:	Modified Francis	
Horsepower, each:	38,000 hp @ 95 feet	
	Turbine Mode	*Pump Mode*
Discharge, each:	———	3,000 cfs
Head:	85 to 102 feet	99 feet (rated)
Speed:	112.5 rpm	112.5 rpm
Maximum Efficiency:	91.0%	92.0%
Governors		
Manufacturer:	Baldwin-Lima-Hamilton Corporation	
Type:	Cabinet-actuator	
System Pressure:	350 psi	
Servo Capacity		
Turbine:	229,000 ft-lbs	
Pump-Turbine:	421,000 ft-lbs	
Full Gate Stroke		
Turbine:	5.75 sec./8 sec. cushion	
Pump-Turbine:	12.5 sec./7 sec. cushion	
Cranes		
150-Ton Powerhouse Bridge Crane		
Manufacturer:	American Crane and Hoist Corporation	
Rated capacity, tons:	150	
Rated capacity of main hoist, tons:	150	
Rated capacity of auxiliary hoist, tons:	25	
25-Ton Draft-Tube Gantry Crane		
Manufacturer:	American Crane and Hoist Corporation	
Rated capacity, tons:	25	
Rated capacity of main hoist, tons:	25	
Rated capacity of auxiliary hoist, tons:	3	
75-Ton Headworks Gantry Crane		
Manufacturer:	American Crane and Hoist Corporation	
Rated capacity, tons:	75	
Rated capacity of main hoist, tons:	75	
Rated capacity of auxiliary hoist, tons:	7½	

Turbine and Pump-Turbines

The turbine is a vertical-shaft Kaplan type and is directly connected to a synchronous generator operating at 138.5 rpm (Figure 179). The pump-turbines are the vertical-shaft modified-Francis type and are directly connected to synchronous motor-generators operating at 112.5 rpm (Figure 180).

Releases from Edward Hyatt Powerplant are the controlling criterion for Thermalito unit operation. Optimum plant efficiency is achieved by pump-turbine operation near the best efficiency point regardless of the number of units in service. Partial loads and load variations are taken primarily by the Kaplan unit.

Figure 179. Kaplan Turbine

Figure 180. Francis Pump-Turbine

Pumping requirements can be met by two of the pump-turbine units at Thermalito, permitting an outage on one unit without affecting pump-back operation at Edward Hyatt Powerplant. The units were designed to allow removal of the turbine parts through the generator stator by the powerhouse bridge crane. The setting of all units is at elevation 121 feet, which provides a minimum submergence of 2 feet at centerline of the distributor.

Wicket-gate restraining mechanisms, similar to those installed on Edward Hyatt Powerplant units, (see Chapter II of this volume) are provided on all the units to prevent cascading failure of shear pins in the wicket-gate linkage. The Kaplan turbine unit has a mechanical overspeed device to limit runaway to not more than 85% above synchronous speed. This device is located in the runner hub and is mechanically actuated by centrifugal force to bypass oil to the blade servomotor causing the blades to go to the full open position.

A problem with the wicket gates was encountered shortly after the Powerplant was placed in service. An obstruction in the wicket gates of one of the pump-turbines caused a shear pin to fail which, in spite of the gate restraining mechanisms, precipitated a cascading failure of eight adjacent shear pins. An extensive test program was initiated to determine and eliminate the cause of the failure. It was found that the wicket-gate restraining mechanisms were incorrectly adjusted due to hysteresis in the load-deflection characteristics of the Belleville springs. Special procedures were developed for the installation and adjustment of the springs; subsequent tests proved the problem to be corrected.

Governors

Each unit is provided with an electrohydraulic, oil-pressure, cabinet-actuator-type governor designed for speed regulation and control of the turbines (Figure 181). The governor is provided with an electrically driven speed responsive element directly connected to the pilot valve for operation of the main oil distributing valve.

The Kaplan governor was designed to accommodate a maximum of six cams to optimize the efficiency over the large range of heads and flow. Initially, three cams were furnished designed from data derived from the model tests.

The final selection of the number and contour of the cams was determined from results of field index tests. These site tests verified that the three cams furnished were sufficient and required no further modification to obtain maximum efficiency. The governor has a motorized actuator to permit selection from the area control center of the proper cam. Local control is accomplished by adjusting the manual cam changing knob on the cabinet. A cam indicator is provided on the control board.

Equipment Handling—Cranes

150-Ton Bridge Crane. General hoisting service for the Powerplant and for assembly and maintenance of the turbine and pump/turbines is provided by a bridge crane (Figure 182). The crane is an electric, cab-operated, overhead, traveling type with a 150-ton main hoist and 25-ton auxiliay hoist mounted on a single trolley.

Figure 181. Governor

Figure 182. Bridge Crane

The rated capacities and speeds are as follows:

Main Hoist	
Capacity:	150 tons
Lift:	65 feet
Hoist speed:	4.7 feet per minute (fpm)
Auxiliary Hoist	
Capacity:	25 tons
Lift:	95 feet
Hoist speed:	30 fpm
Bridge speed:	75 fpm
Trolley speed:	30 fpm
Bridge span:	58 feet-4 inches
Trolley span:	13 feet-6 inches
Bridge travel:	318 feet

75-Ton Headworks Gantry Crane. The headworks gantry crane services the full length of the headworks structure and is used for installing and removing the intake gates, intake stoplogs, bypass stoplogs, and for trashrack handling or cleaning (Figure 183). The crane also operates the intake gates during emergency closure of the penstocks. The intake gate lifting beam is normally attached to the main hoist except while the crane is being used for installation or removal of stoplogs for the plant bypass gate. A 7½-ton, auxiliary, monorail hoist mounted on the crane is used for handling the intake trashrack sections. A manually operated rail clamp is provided on each front gantry truck to prevent accidental movement of the crane.

Figure 183. Headworks Gantry Crane

The rated capacities and speeds are as follows:

Main Hoist	
Capacity:	75 tons
Lift:	70 feet
Hoist speed:	5 fpm
Trolley speed:	5 fpm
Auxiliary Hoist	
Capacity:	7½ tons
Lift:	85 feet
Hoist speed (2 speed):	10–30 fpm
Trolley speed:	40 fpm
Gantry Travel:	284 feet
Gantry Speed:	50 fpm

25-Ton Draft-Tube Gantry Crane. The crane operates on rails which extend the full length of the plant and is used for installing and removing the draft-tube bulkhead gates (Figure 184). The draft-tube gate lifting beam is permanently attached to the main hoist. A 3-ton, auxiliary, monorail hoist mounted on the crane is used for handling the draft-tube trashracks and draft-tube trashrack hoist equipment.

Figure 184. Draft-Tube Gantry Crane

The rated capacities and speeds are as follows:

Main Hoist	
Capacity:	25 tons
Lift:	82 feet
Hoist speed:	16 fpm
Auxiliary Hoist	
Capacity:	3 tons
Lift:	90 feet
Hoist speed:	20 fpm
Gantry Travel:	283 feet
Gantry Speed:	75 fpm

Auxiliary Service Systems

The auxiliary service systems at the plant are detailed in Chapter I of this volume with two exceptions: (1) air-conditioning system, and (2) raw water system.

Air-Conditioning System. The main air-conditioning system differs from systems used at other plants in that forebay water is used as the cooling medium. Forebay water, which exists at an appropriate temperature and pressure, was selected in lieu of refrigeration compressors after careful investigation and economic evaluation.

In order to provide maximum comfort for personnel, the control room, records room, and communications room were air-conditioned by a conventional refrigerated system with separate supply and return ducts. The main system heating is provided by individual electric duct heaters. No heating is provided in the control room since the heat gain from the lighting fixtures and electrical equipment is ample.

Raw Water System. The raw water system differs from that used at other plants. Each unit has two raw water intakes: one is located on the spiral case, and the other is located on the penstock ahead of the stoplog gate slot. The spiral case intake supplies the generator cooling requirements. The primary function of the forebay intake is to supply water for filling the penstocks. Units Nos. 1 and 4 have an additional branch line from the forebay intake to supply an auxiliary raw water header in the Powerplant. This header supplies the cooling water requirements of the auxiliary equipment and that required by the bearing cooling coils and the runner seals for the units.

Various schemes such as pumping from the afterbay were studied for supplying raw water. The forebay was selected as the raw water source over pumping from the afterbay because it provides a relatively constant and adequate pressure, is highly dependable, and is economical.

Electrical Features

General

The electrical installation includes the generator, motor-generators, power transformers, 230-kV switchyard equipment, and control and auxiliary systems.

General descriptions of electrical systems which are common to other plants are contained in Chapter I of this volume.

Description of Equipment and Systems

Three motor-generators and one generator were installed. Each machine winding is wye-connected with the neutral connected to ground through the high-voltage winding of a distribution transformer. A resistor and relay are connected in the low-voltage winding of the transformer. This combination limits the magnitude of unbalanced and ground-fault currents and also trips the breaker under these conditions. The motors are started full-voltage with the pump-turbine casing dewatered.

A 13.8-kV system is used to connect the generator, motor-generators, and station service to the power transformers. Metal-clad circuit breakers are utilized to operate and protect the equipment connected to this system. Station service supply is received normally from the power transformers (Figure 185). Surge protection was installed for each generator and motor-generator.

Energy to or from the plant, depending on the mode (pumping or generating), is carried on two transmission lines. The lines are tapped into the interconnection serving Edward Hyatt Powerplant and the Pacific Gas and Electric Company's Table Mountain Substation. Each line is terminated with a circuit breaker. Four power transformers are connected to the 230-kV bus with disconnect switches and are protected by lightning arresters.

Station service is distributed throughout the plant at 480 volts. Auxiliary station service systems, protective relaying, metering, and the control system complete the electrical systems.

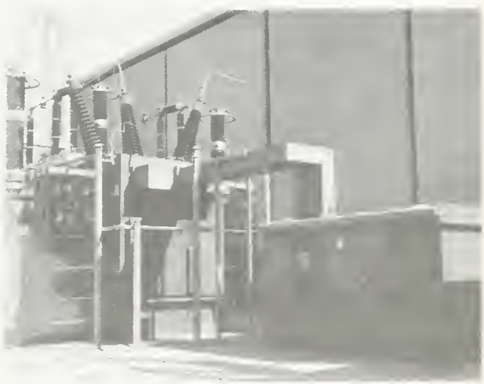

Figure 185. 35-MVA Transformer and 15-kV Switchgear

Equipment Ratings

Generator and Motor-Generators

Manufacturer: Allis-Chalmers Manufacturing Company

Type: Vertical-shaft, synchronous, 3-phase, 60 Hz

Generator No. 1

Capacity: 34,316 kVA
Speed: 138.5 rpm
Power factor: 95%
Volts: 13,800

Motor-Generators Nos. 2, 3, and 4

Generator

Capacity: 30,555 kVA
Speed: 112.5 rpm
Power factor: 90%
Volts: 13,800

Motor

Horsepower: 40,000
Speed: 112.5 rpm
Power factor: 100%
Volts: 13,200

Power Transformers

Number of transformers: 4
Manufacturer: Westinghouse Electric Corporation
Volts: 230-13.2 kV grounded-wye
Taps: In the high-voltage winding, 2½ and 5% above and below 230 kV
Phase: 3
Frequency: 60 Hz
Type: OA/FA
Connections: Wye-Delta

Transformer No. 1

Capacity: 26,250/35,000 kVA

Transformers Nos. 2, 3, and 4

Capacity: 24,400/32,500 kVA

Station Service Transformers

Number of transformers: 4
Volts: 13,800—480Y/277
Phase: 3
Frequency: 60 Hz
Capacity: 500 kVA
Type: Self-cooled, dry

Generator and Motor-Generators

Mechanical characteristics were matched to the turbine and pump-turbines; maximum capacity of the motor-generators was established by required motor output at the highest pumping head (maximum horsepower conditions). Unity power factor and maximum temperature rise were established at the maximum horsepower requirement. Since operation at this head would occur only at intervals, the motor would have capability to operate with a leading power factor at decreased load. Actual operating conditions should allow the motor to operate at a lower temperature with a correspondingly longer life. Since the electrical capacity of the motor-generators was determined by the motor conditions, surplus capacity was available in the generator. The machine was specified for 90% power factor to acquire a large exciter. This rating provided future flexibility to operate the generators at an increase in watt or var output depending on system requirements (Figures 186 and 187).

Figure 186. Unit No. 1 Exciter

Figure 187. Generator Excitation Equipment

All machines are equipped with a single guide bearing which, with the thrust bearing, is located below the rotor. Plants with relatively low head, low speed, and large water passages provide more space for installation of umbrella-type generators and removal of thrust bearings without problems. Economics favored the umbrella machine for installation at Thermalito Powerplant, making it the only plant in the Project with this design.

Motor Starting Method

Motors are started with full voltage applied to the terminals. The pump-turbine casing is dewatered to reduce starting and pull-in torques. After water is depressed, the motor is started and accelerated as an induction machine to approximately 95% rated speed, at which point the direct-current field is applied and the motor synchronizes. Air is purged from the pump-turbine casing and the unit is placed in operation by opening the wicket gates.

Starting duty for these motors is not considered to be as severe as for the major pumping plants which are started daily for off-peak pumping. The Hyatt and Thermalito units are expected to operate only part of the year as pumps and may not be operated in the pumping mode during some years when water conditions are favorable. Since full-voltage starting is the most simple and reliable, this starting method was selected.

High-Voltage System

The switchyard consists of a single bus located on the transformer deck of the powerhouse and a line breaker structure. Circuit breakers (230 kV) terminate the two transmission lines. Four power transformers are connected to the bus by means of load-interrupter switches. Adequate protection is provided for power transformers with 13.8-kV breakers on the low-voltage side and line breakers on the high-voltage. A transformer can be removed from service by the load-interrupter switches after its load is removed. This arrangement provided a minimum facility with adequate operating and protective capabilities.

Two transmission lines serve the Powerplant. They are tapped into two of the three lines between Edward Hyatt Powerplant and Pacific Gas and Electric Company's Table Mountain Substation and are approximately 2½ miles long. One transmission line would have been adequate for the capacity of the plant; however, two were constructed to give greater reliability. Since Hyatt and Thermalito operate together, continuity of service became more important than normal for a plant of this capacity.

Control System

The control system provides for attended operation from the control room of the plant or from the switchboards (Figure 188). It also provides for fully remote operation from the area control center and emergency control room at Edward Hyatt Powerplant. The remote supervisory control system is described more fully in Volume V of this bulletin. Normal operation of Thermalito will be remote; consequently, all functions, operating modes, and annunciation were designed for the plant being unattended. Auxiliaries as well as main units are thus controlled. Local controls were intended for initial start-up, emergency operation, and maintenance functions.

Station Service System

Station service power is supplied by four 13,800-480 volt transformers connected to the low-voltage bus of the power transformers (Figure 189). Each of the two 480-volt distribution boards are supplied by two of the station service transformers (Figure 190). These two

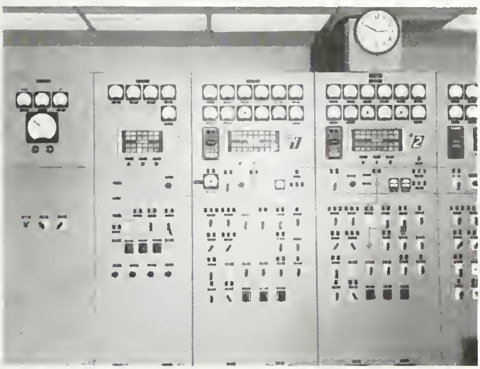

Figure 188. Plant Control Switchboard

Figure 189. 15-kV Station Service Switchgear

boards distribute 480-volt power to motor control centers and load centers located throughout the plant adjacent to the loads. One feeder circuit from each of the two distribution boards is connected to each of the motor control and load centers (Figure 191). This arrangement provides service throughout the plant from any one of the four power and station service transformers.

A standby service at 12 kV has been provided by Pacific Gas and Electric Company. The line is connected through selective switching to one of the four station service transformers. An induction voltage regulator was required in the standby circuit to adjust and stabilize the voltage.


Figure 190. 300-kVA Station Service Substation


Figure 191. 480-Volt Distribution Center

Construction

Contract Administration

General information for the major contracts for construction of Thermalito Powerplant is shown in Table 3. The principal construction contract was designated Specification No. 64-37 and included excavation, concrete and structural steel construction, and some mechanical and electrical work. Furnishing and installing of major equipment was by separate contracts.

Excavation

Stripping. Stripping operations started December 11, 1964 in the approach channel area (Figure 192). The overburden, which was mud at that time, was dozed downhill until the basalt was uncovered. The basalt was used to surface the haul roads. Stripping operations progressed ahead of general excavation from the approach channel across the headworks area to the powerplant tail channel area.

TABLE 3. **Major Contracts—Thermalito Powerplant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Turbines, pump-turbines, and governors	63-39	$3,766,785	$3,877,408	$174,350	2/25/64	9/20/68	Allis-Chalmers Mfg. Co.
Thermalito Powerplant (structure)	64-37	15,248,037	17,011,772	1,214,876	12/ 4/64	1/24/69	Guy F. Atkinson Co.
Generator and three motor-generators	65-02	2,150,000	2,248,117	9,436	6/ 3/65	2/ 9/68	Allis-Chalmers Mfg. Co.
Power transformers	65-34	536,631	552,726	−510	8/19/66	11/26/68	Westinghouse Electric Corp.
Station service secondary unit substation	65-57	77,000	77,756	--	2/ 8/66	7/ 5/68	Golden Gate Switchboard Co.
Generator, 13.8-kV switchgear and bus	65-58	207,585	213,699	170	4/28/66	7/ 8/68	I.T.E. Circuit Breaker Co.
Motor control centers	66-08	25,146	26,152	--	4/27/66	4/ 5/68	Consolidated Electrical Distributors
Main control and recording switchboards	66-09	154,702	174,450	12,813	4/15/66	11/ 4/68	Westinghouse Electric Corp.

Figure 192. Stripping Operation in the Approach Channel Area

Figure 193. Excavation for Headworks Structure

Approach Channel. Approach channel excavation started shortly after the stripping operation and was initially accomplished with a single-tooth parallelogram ripper attached to a dozer. Materials in the weathered zones of basalt were loaded and hauled with rubber-tired scrapers. Drilling and blasting were required when the basalt became fresh and tight. The contractor delayed completion of excavation until the fall of 1967 so that he was able to place the material directly into a fill being constructed under another contract.

Ground water from intermittent springs was encountered in the approach channel excavation at the base of the upper basalt. Uplift pressure relief holes were drilled from the grout gallery, angled downstream from the grout curtain. Holes were drilled to a minimum depth of 50 feet so that they passed through the pervious zones adjacent to the Lower Interflow and penetrated 5 feet into tight hard rock of the Lower Basalt Flow. Ten piezometer wells, two per concrete monolith, were drilled in the pervious zones.

Tail Channel. Common earth materials and cemented gravels were excavated from the tail channel with rippers and scrapers pushed by tandem push tractors. Ground water drainage was required to complete the channel excavation.

Headworks. The headworks foundation was excavated by drilling and blasting and by the use of scrapers and push tractors. The foundation was successfully shaped by line drilling (Figure 193). Final loading and hauling were done with rubber-tired equipment to avoid disturbing the foundation. Compressed air and hand tools were used for final cleanup.

Penstocks. Penstock excavation was done with the same equipment as that used in the headworks area except that more handwork was required in preparing the finished grade. Excavation was shaped by first cutting benches in the transverse direction followed by cutting slots for the penstocks from the top down.

Penstock excavation was modified two times because of unstable material. Initially, benches between elevations 100 and 162 feet were removed. Later, excavation was extended back to a stable face beyond a shear zone. Because of the steep excavation slopes in the penstock area, the headworks was moved 30 feet upstream away from the steep face.

Powerhouse. Main excavation for the powerplant area was performed with the same equipment and by the same methods as used for channel excavation. Final shaping of the powerhouse foundation was done with backhoes, and the material was hauled with dump trucks.

Powerhouse excavation was terminated at elevation 72 feet when plate bearing tests revealed adequate foundation.

Foundation Preparation

Foundations of the approach channel dam and wingwall were similarly prepared. After excavation was completed and before final cleanup, the foundation was grouted. Foundation grouting for the intake structure was done from the gallery after the concrete was placed.

Blanket grout holes were drilled 25 feet deep on about 25-foot centers. All holes were drilled in the relatively impervious Middle Basalt Flow. Holes were aligned to cross steeply dipping regional joints, but most of these were filled with clay and were tight with only 8 of 72 holes drilled and tested requiring grouting.

The curtain was stage-grouted in three zones, with the bottom zone extending beyond the Lower Interflow. The 5-foot maximum hole spacing specified for Zone 1 was changed to 10 feet after blanket grouting and initial curtain grouting revealed the surface rock to be relatively impervious. Zone 1 was grouted from the nipple; lower zones were generally grouted through a packer to prevent uplift of surface rock.

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Holes were washed and water-tested before grouting to determine a suitable starting grout mix. Grouting pressures equivalent to one pound per square inch per foot of depth were used. Any stage which took less than 0.1 cubic foot per minute when water-tested was not grouted. The grout curtain extended to a depth of 64 feet below the foundation. This curtain was extended under the main forebay dam as described in Volume III of this bulletin.

The foundation for the powerhouse did not require special treatment. Wingwall foundations were basalt and required only standard cleanup prior to placing concrete.

Concrete

Production. Sand was obtained from the Cherokee placer mine located approximately 12 miles north of Oroville, and coarse aggregate was obtained from the Union School pit located in the dredger tailings approximately 10 miles south of Oroville. Fine aggregate was processed to specified gradation by a 9-inch Station Classifier, with twin-wash screws. Aggregates were hauled to the project in bottom-dump trucks and stored in five 240-cubic-yard bins. The 6-inch and 3-inch aggregates were lowered into their respective bins by means of rock ladders.

Corrugated-metal roofing was placed over exposed material in the bins and over the conveyor belt for shading the aggregate. Aggregate bins were painted white to relect heat.

Batch Plant. The contractor erected a fully automatic batch plant using four 2-cubic-yard tilting mixers, individual beam scales, and weigh hoppers for each size of aggregate, cement, pozzolan, ice, and water.

Concrete aggregate, except for sand, was rewashed on vibrating screens in the conveyor system delivering the material to the batch plant bins. Ice was delivered in 300-pound blocks and stored in three refrigerated freight cars. Blocks were pulled from the cars by hand and fed into an ice crusher. Chipped ice was moved to a 40-cubic-foot storage tank and fed into the weigh hopper by screws. Water was obtained from a well the contractor drilled near the site. Pozzzlan, a water-reducing admixture, and an air-entraining agent were included in the concrete mix.

Strict quality and quantity control was maintained at all times over concrete aggregate, cement, and admixtures. Concrete mixing times and temperatures were carefully monitored and controlled.

Transportation. Concrete was dumped directly from the "gob-hopper" into 4-cubic-yard buckets located on a flatcar. The flatcar was towed by a diesel locomotive to where the buckets were lifted by one of two 40-ton gantry cranes which traveled on a trestle that traversed the Powerplant. Each bucket was transported to the placement where its compressed air-operated gates were controlled by a laborer (Figure 194).

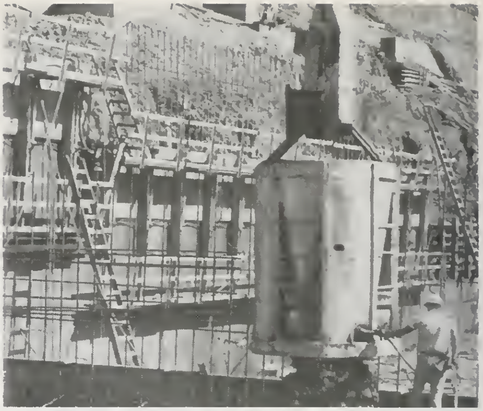

Figure 194. Concrete Placement

In areas not accessible to the gantry cranes, notably the two tailrace retaining walls, approach channel dam, and wingwall, concrete was transported by modified trucks, each carrying two 2-cubic-yard buckets. The buckets were then handled by a 45-ton crane.

Placement. All construction joints, vertical as well as horizontal, were cleaned by wet sandblasting and by washing thoroughly with air and water jets. The contractor sandblasted at the latest possible time prior to placing of concrete to prevent coloration caused by "bloom" or "carbonation".

Mass concrete mixes contained 6-inch maximum size aggregate and structural concrete mixes, usually $1\frac{1}{2}$-inch maximum size aggregate. All mass concrete was consolidated by means of 6-inch vibrators, and smaller vibrators were used in structural concrete where applicable. In general, consolidation was good, with "rock pockets" being held to a minimum (Figure 195).

Concrete outside and around the scroll case was carefully placed to prevent movement of the scroll case. It was tremied into place until the placement was over the top of the scroll case. Lifts were limited in height, the first being placed to about 1 foot above the bottom of the scroll case, the next 18 inches higher, and the third 4 feet - 6 inches higher. Above this, height of the lifts was controlled by other factors.

After concrete had been placed over the top of the scroll case, it was then placed through bent pipes located around the scroll case to fill the space under the stay ring. After concrete under the stay ring had set for a minimum of seven days, expanding aluminum grout was forced through grout holes in the stay ring. During placing and curing of concrete around the scroll case, draft-tube liner, and pit liner, water was sprayed continuously against the inside metal sur-

Figure 195. Consolidation of Concrete Placement

faces to carry away the heat of hydration. For this area, a special series of mixes was designed that had a lower heat of hydration than the structural concrete mixes.

Temperature Control. The temperature of concrete placed was as near 50 degrees Fahrenheit as could be obtained by using ice up to the full amount of additive water and shading the aggregate on the day it was to be batched for concrete. When the temperature became extremely high and a large volume of concrete was mixed, these methods did not maintain the desired concrete temperatures; however, by installing sprinklers on all coarse aggregate stockpiles, the concrete temperature was held to a maximum of 50 degrees Fahrenheit during prolonged hot weather.

During concrete placements, exposed layers of mass concrete were continuously cooled with fog sprays, and mass concrete placements were allowed only between two hours before sunset and two hours after sunrise.

Curing and Shading. Most concrete was cured by flooding the top of the placement as soon as possible and by applying water to vertical surfaces with perforated plastic pipes as soon as forms were stripped. When the glue-laminated 2-inch by 4-inch forms were used, they were loosened enough the day after concrete placement so water could run between the form and the concrete. In general, curing of concrete was satisfactory.

Between May 1 and October 1, permanently exposed and upstream surfaces of mass concrete, including forms, were shaded with 18 to 24 inches of air space for not less than 28 days. To achieve this, the contractor used burlap supported on wood frames for exposed sloping surfaces, and burlap hung from the forms for vertical surfaces. As forms moved upward for succeeding lifts, additional burlap was added to the bottom of the previously hung shading material (Figure 196).

Other Construction

The powerhouse bridge crane was delivered with temporary motors because of a strike at the motor supplier's plant. Use of temporary motors enabled equipment installation inside the plant to proceed with a minimum delay.

All field welds made during installation of the penstock liners were X-ray tested.

Some gates and gate guides required minor modifications during and after construction before operating satisfactorily.

The three pump-turbines and the Kaplan turbine were installed by Chicago Bridge and Iron Company of Oak Brook, Illinois.

The three motor-generators and one generator were installed by the Eagle Construction Company of Loveland, Colorado.

Erection of the plant superstructure was routine.

Figure 196. Shading of Concrete and Form Surfaces

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 197 through 228).

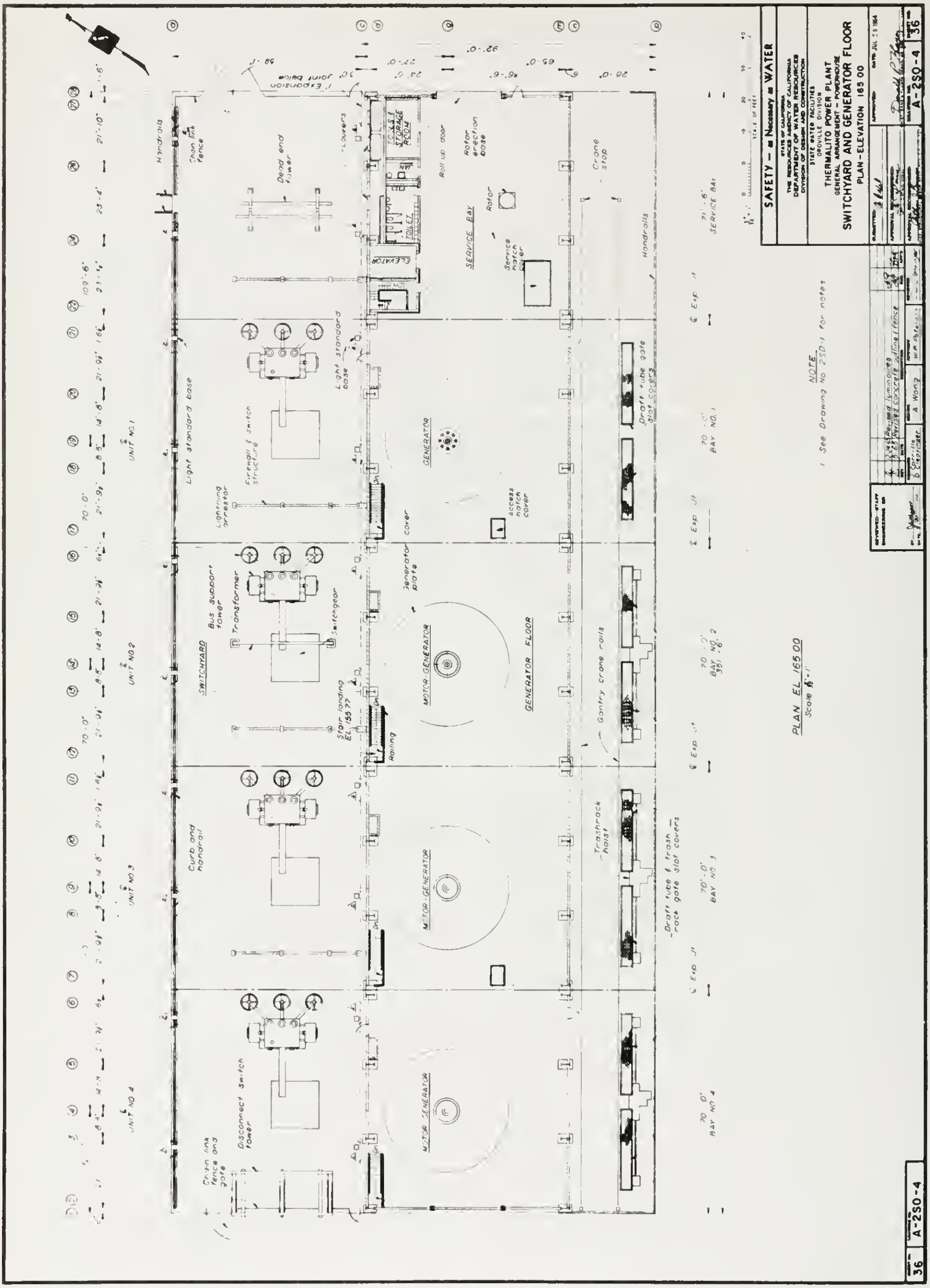

Figure 197. Switchyard and Generator Floor

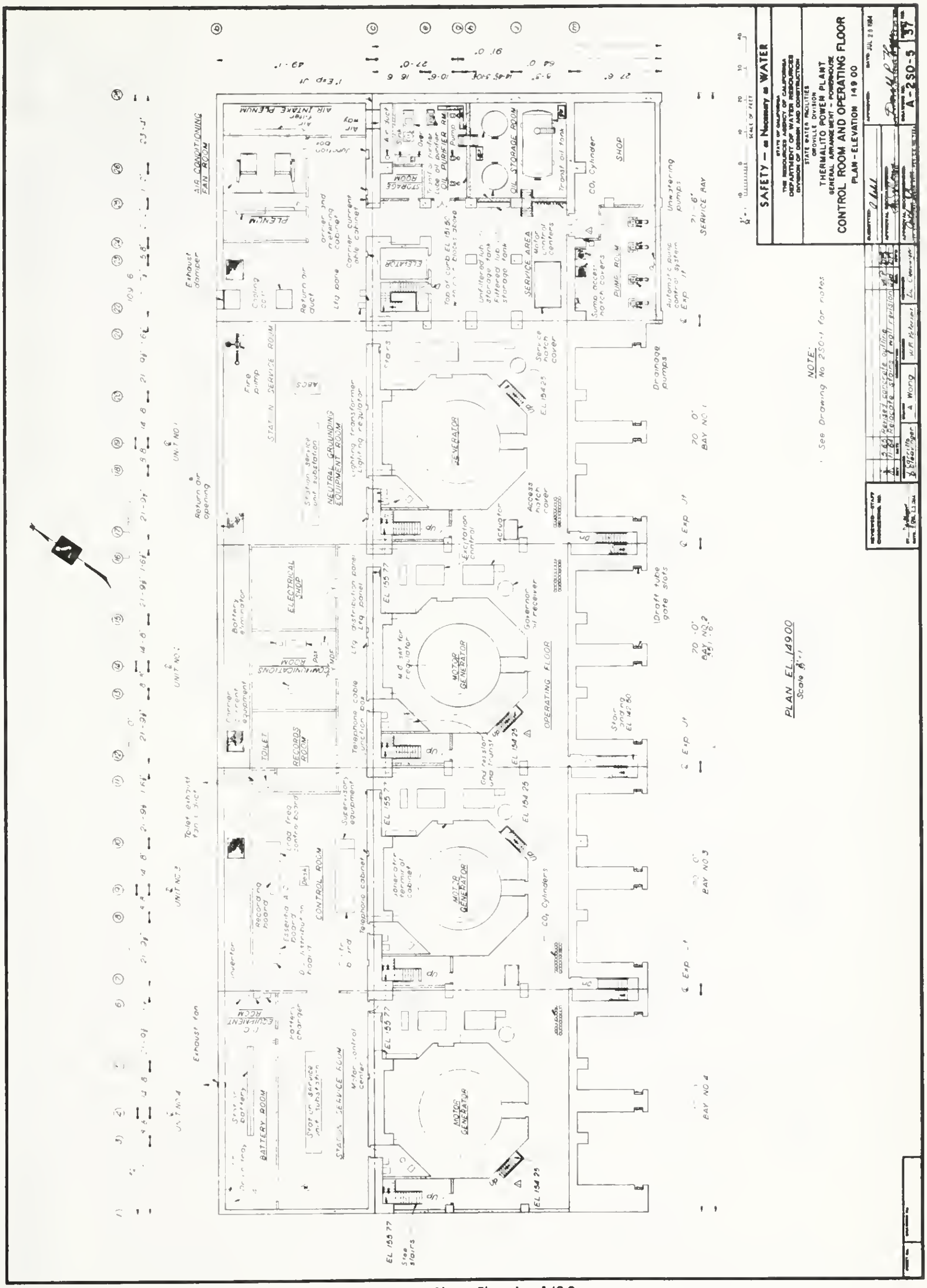

Figure 198. Plan—Elevation 149.0

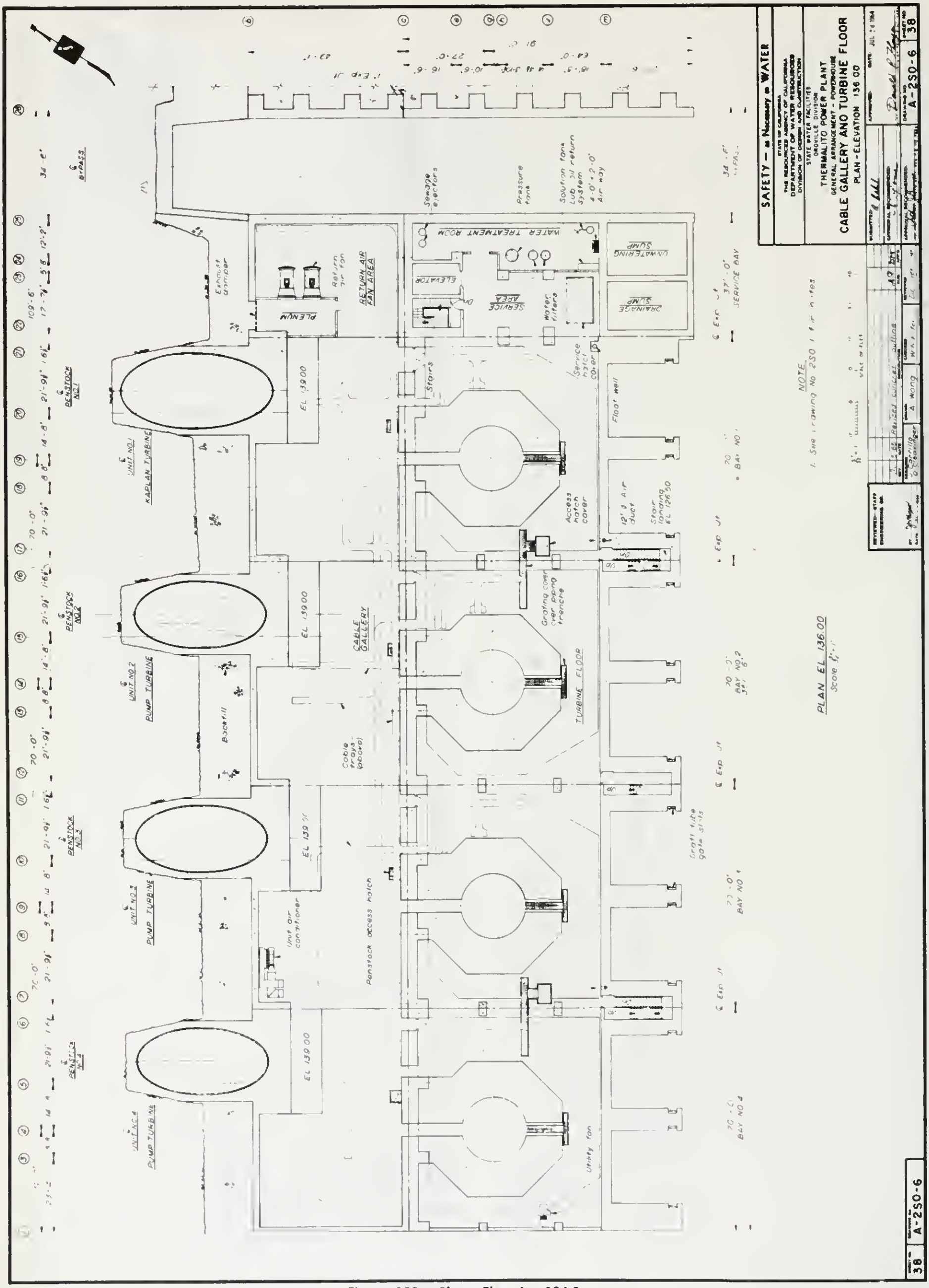

Figure 199. Plan—Elevation 136.0

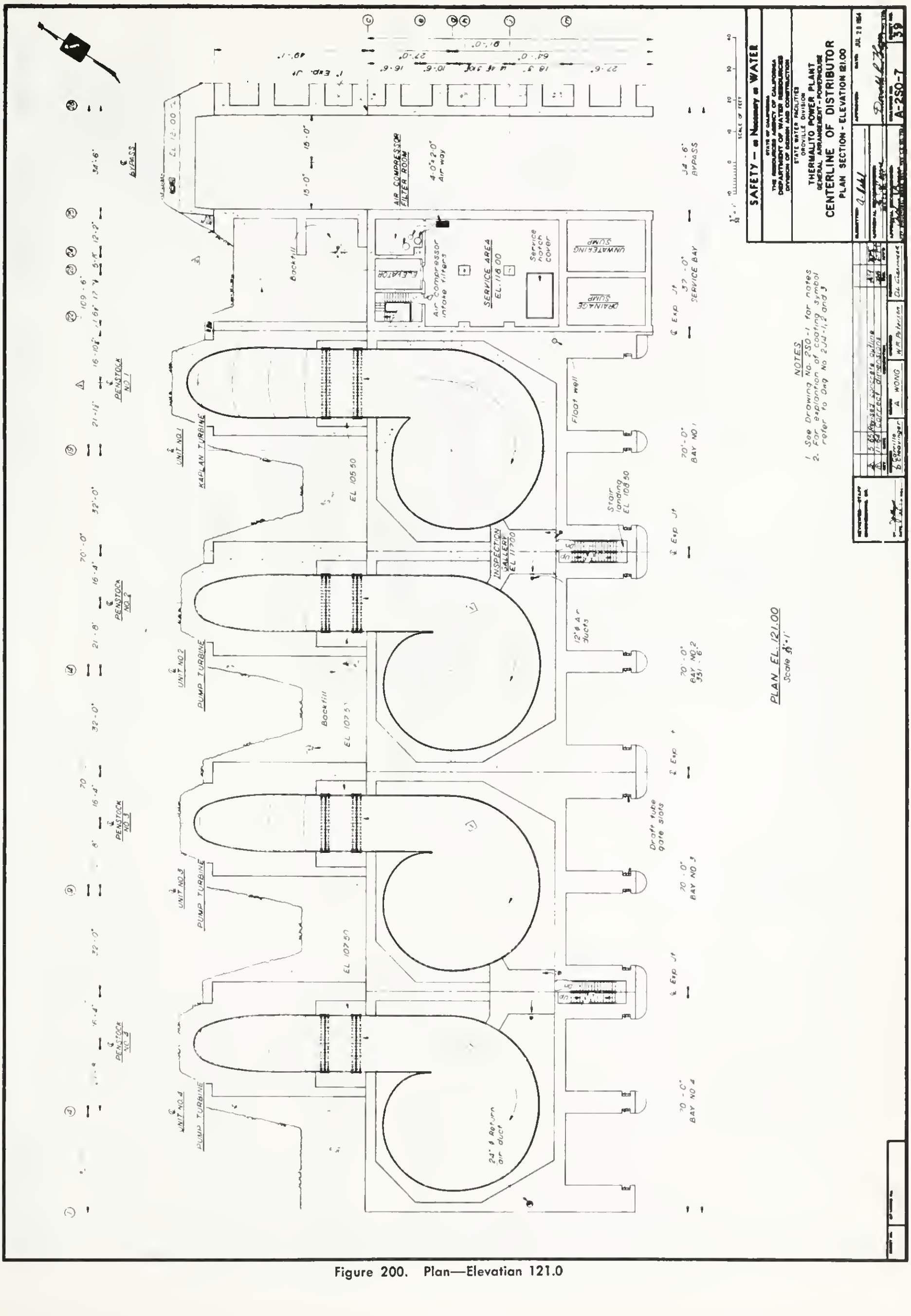

Figure 200. Plan—Elevation 121.0

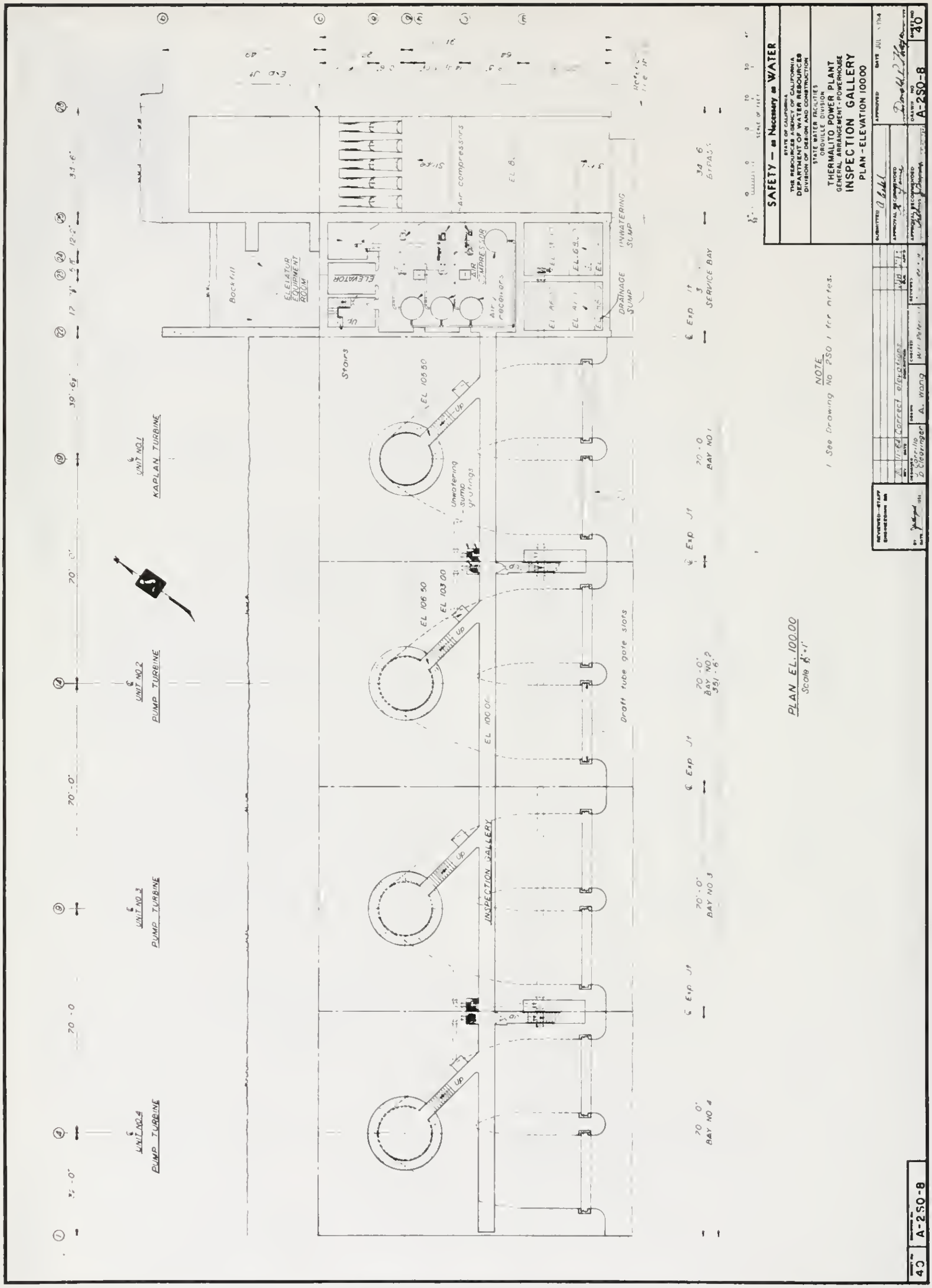

Figure 201. Plan—Elevation 100.0

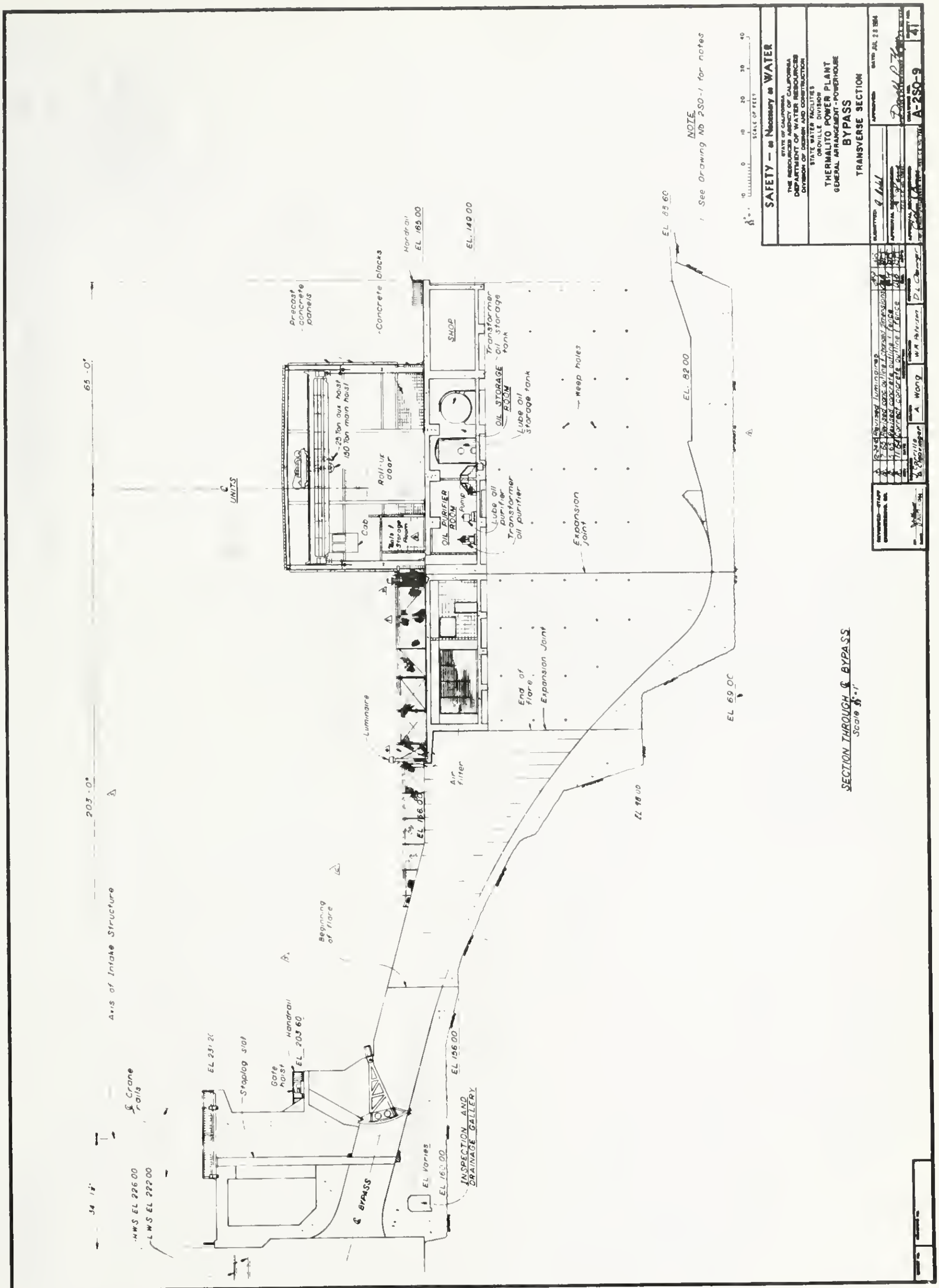

Figure 202. Transverse Section—Bypass

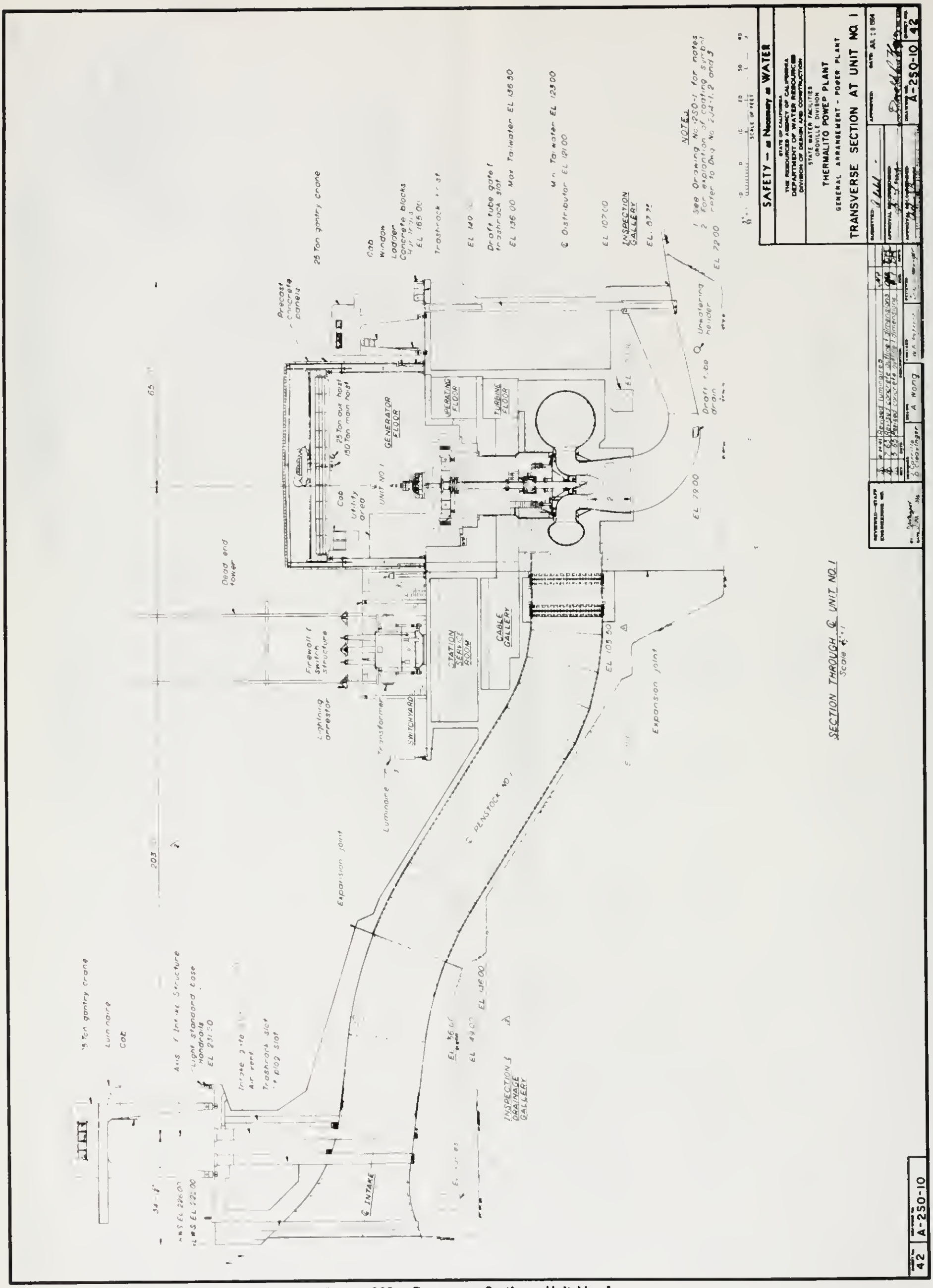

Figure 203. Transverse Section—Unit No. 1

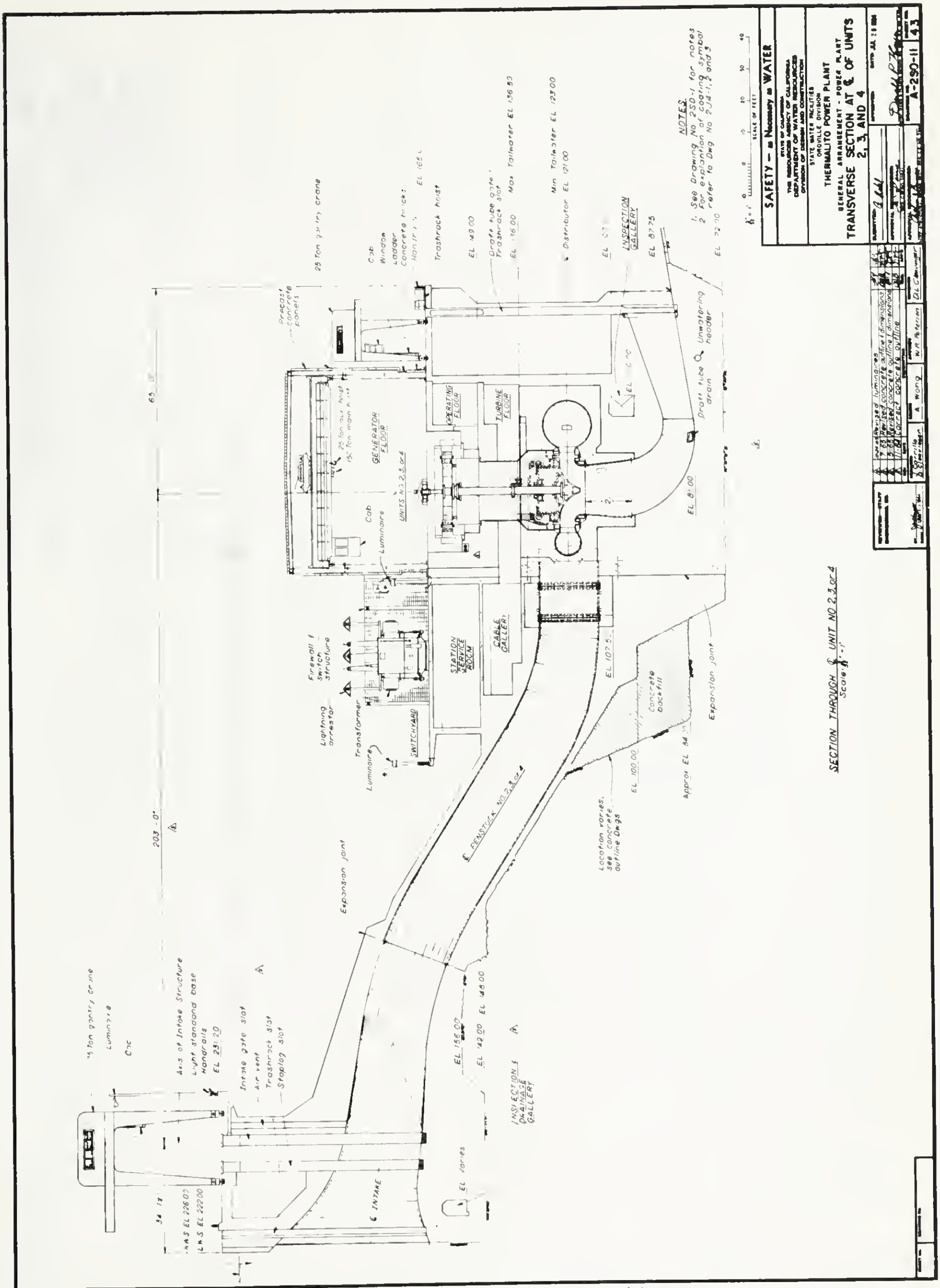

Figure 204. Transverse Section—Units Nos. 2, 3, and 4

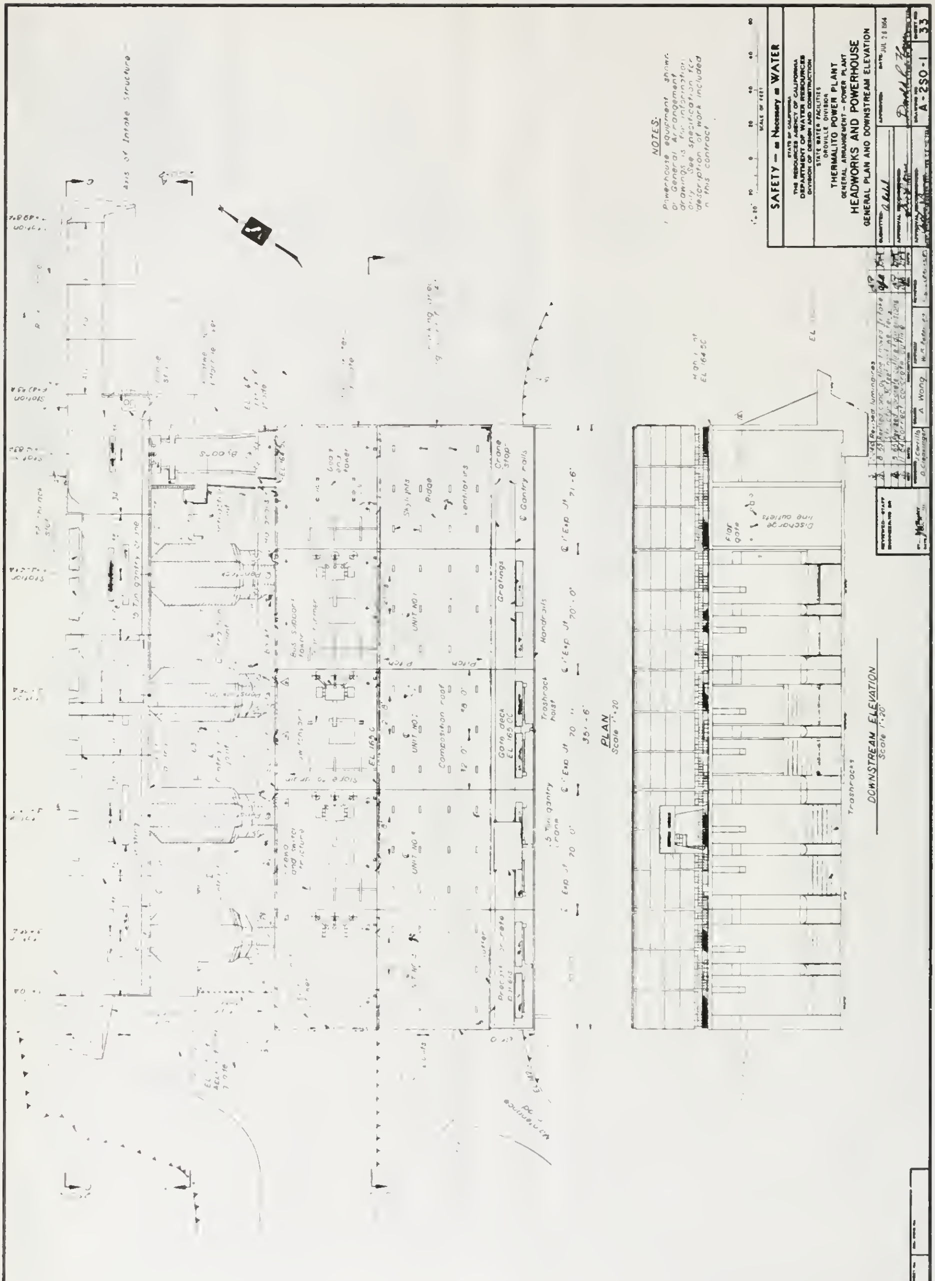

Figure 205. Headworks and Powerhouse—Plan and Elevation

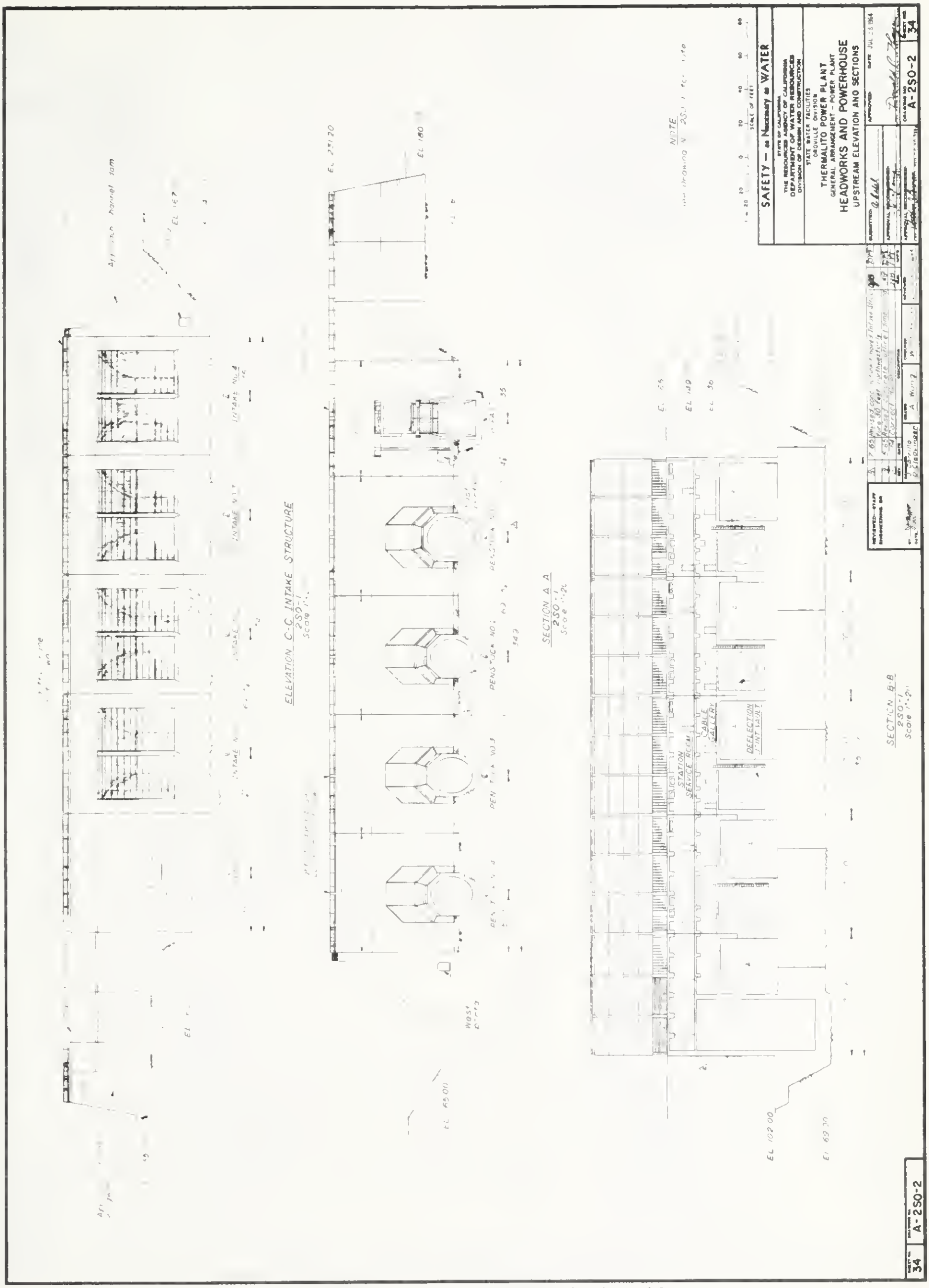

Figure 206. Headworks and Powerhouse—Upstream Elevation and Sections

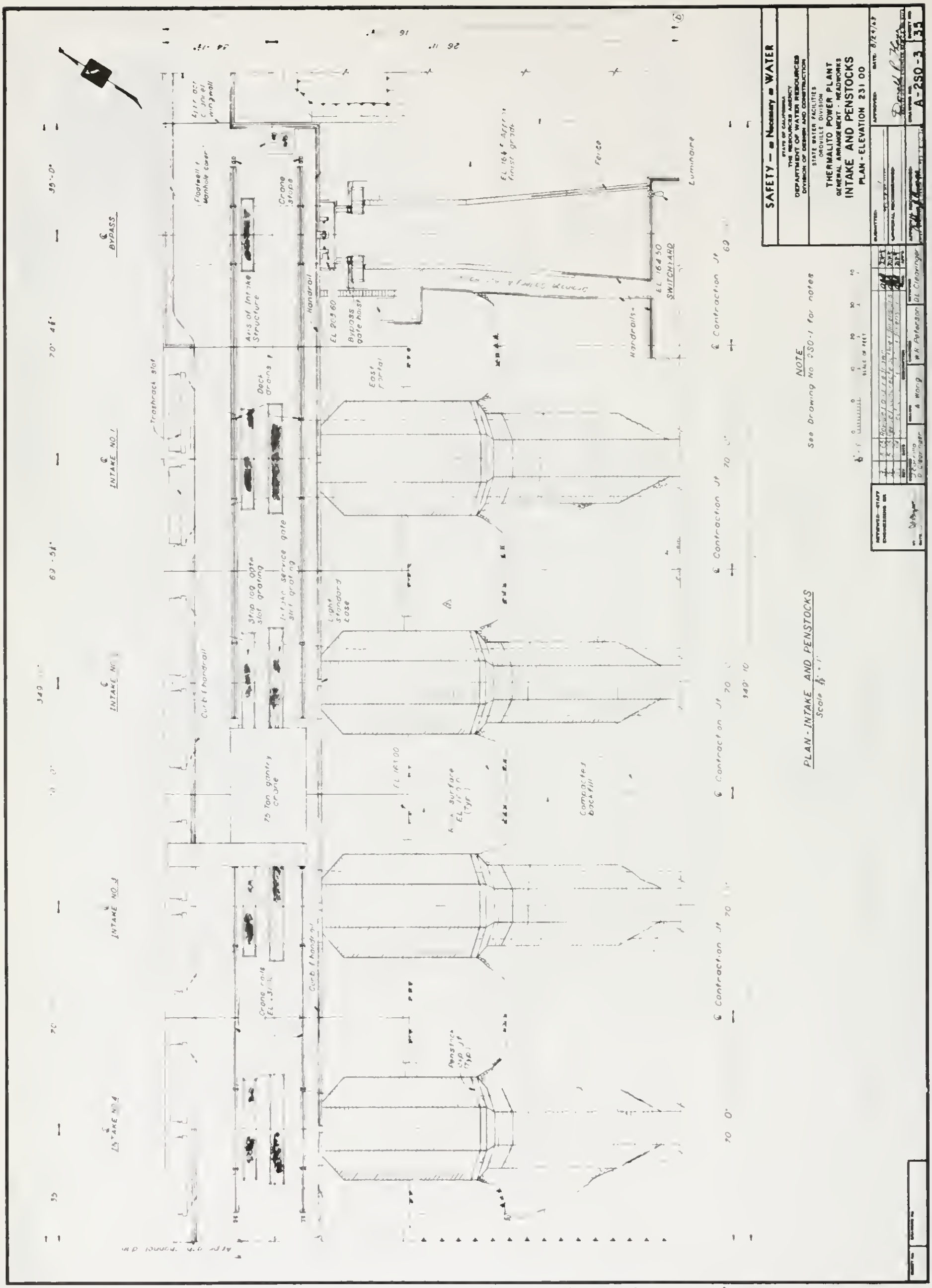

Figure 207. Intake and Penstocks—Plan—Elevation 231.0

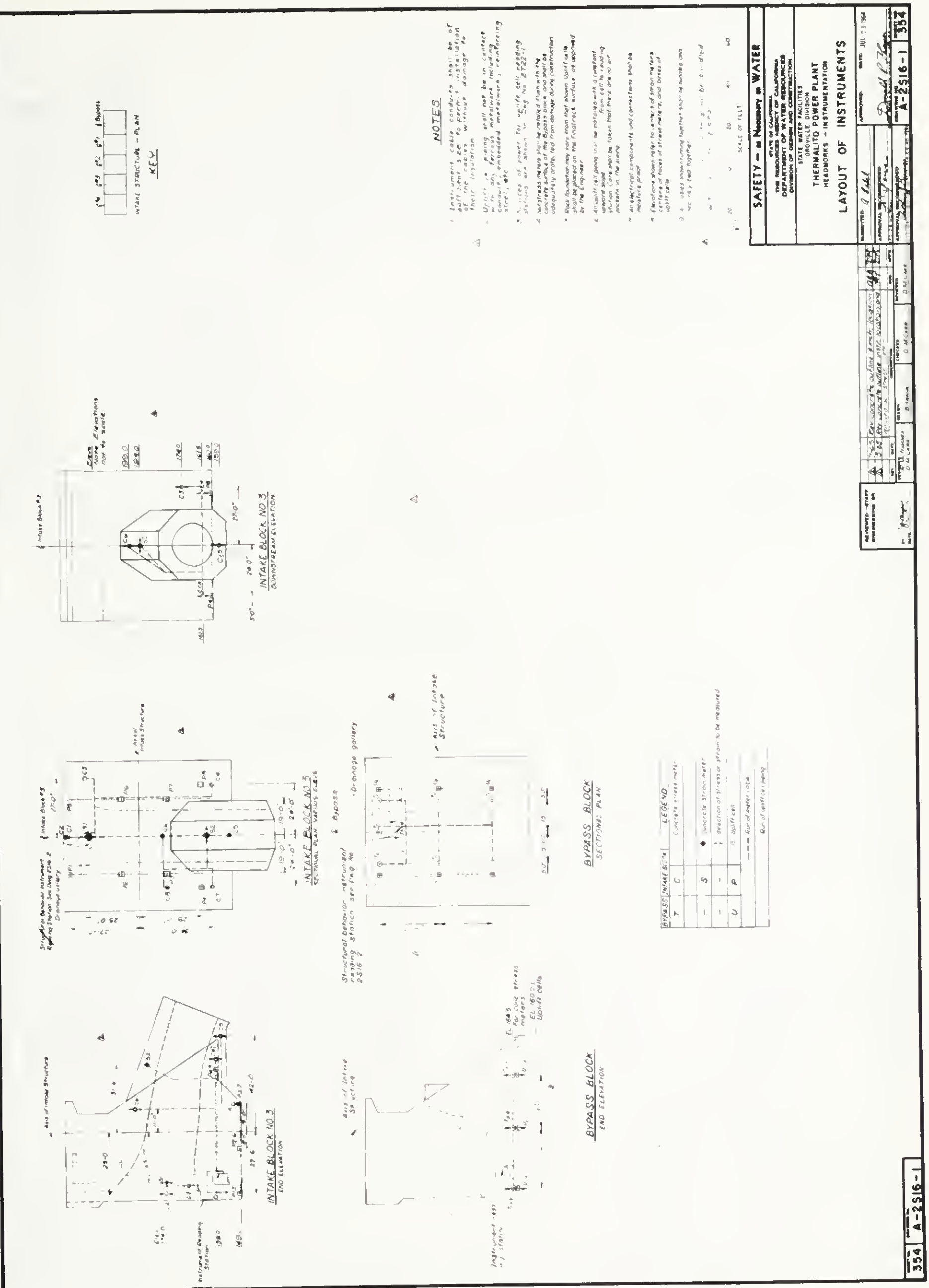

Figure 208. Headworks—Instrumentation

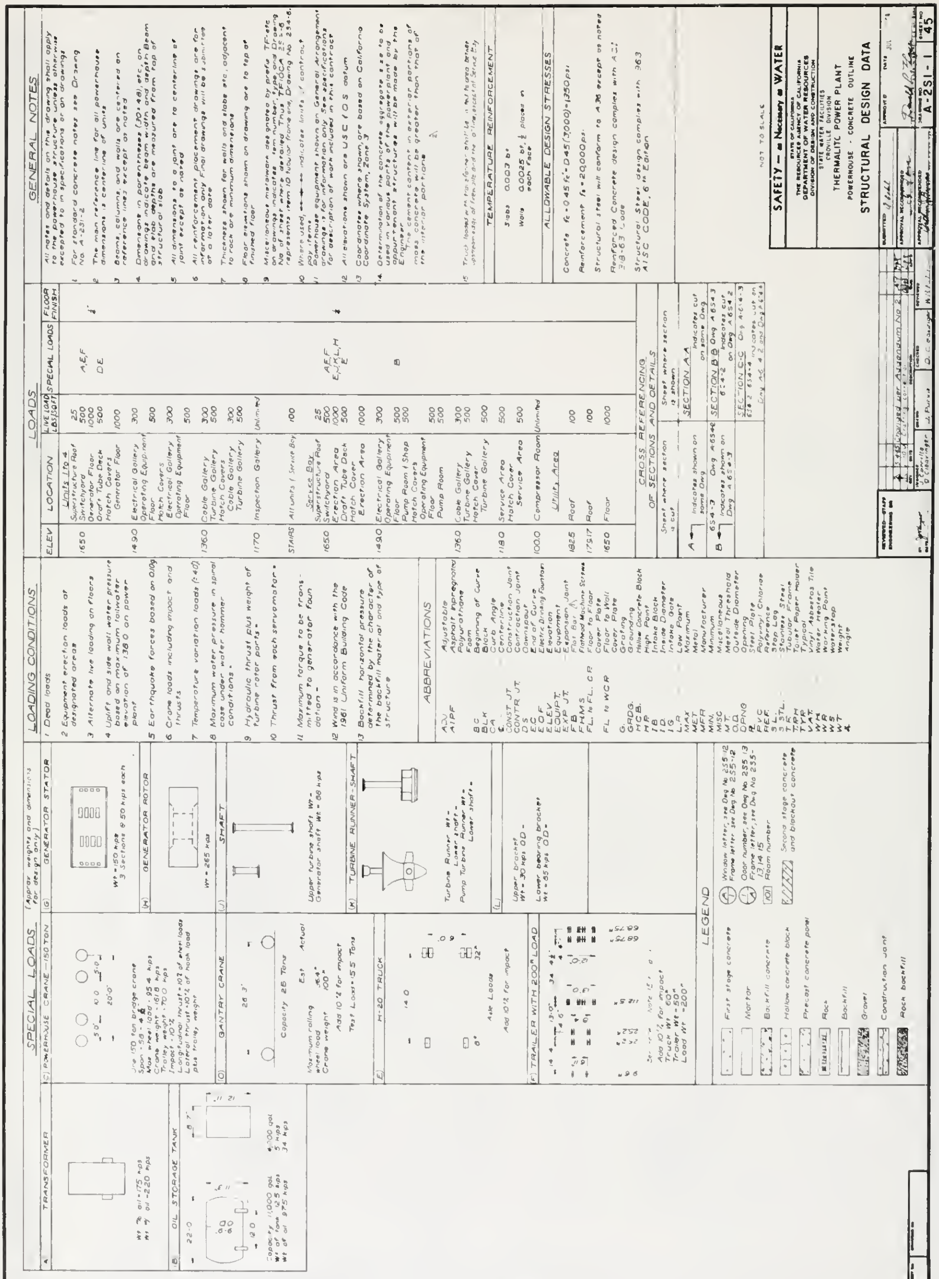

Figure 209. Powerhouse—Structural Design Data

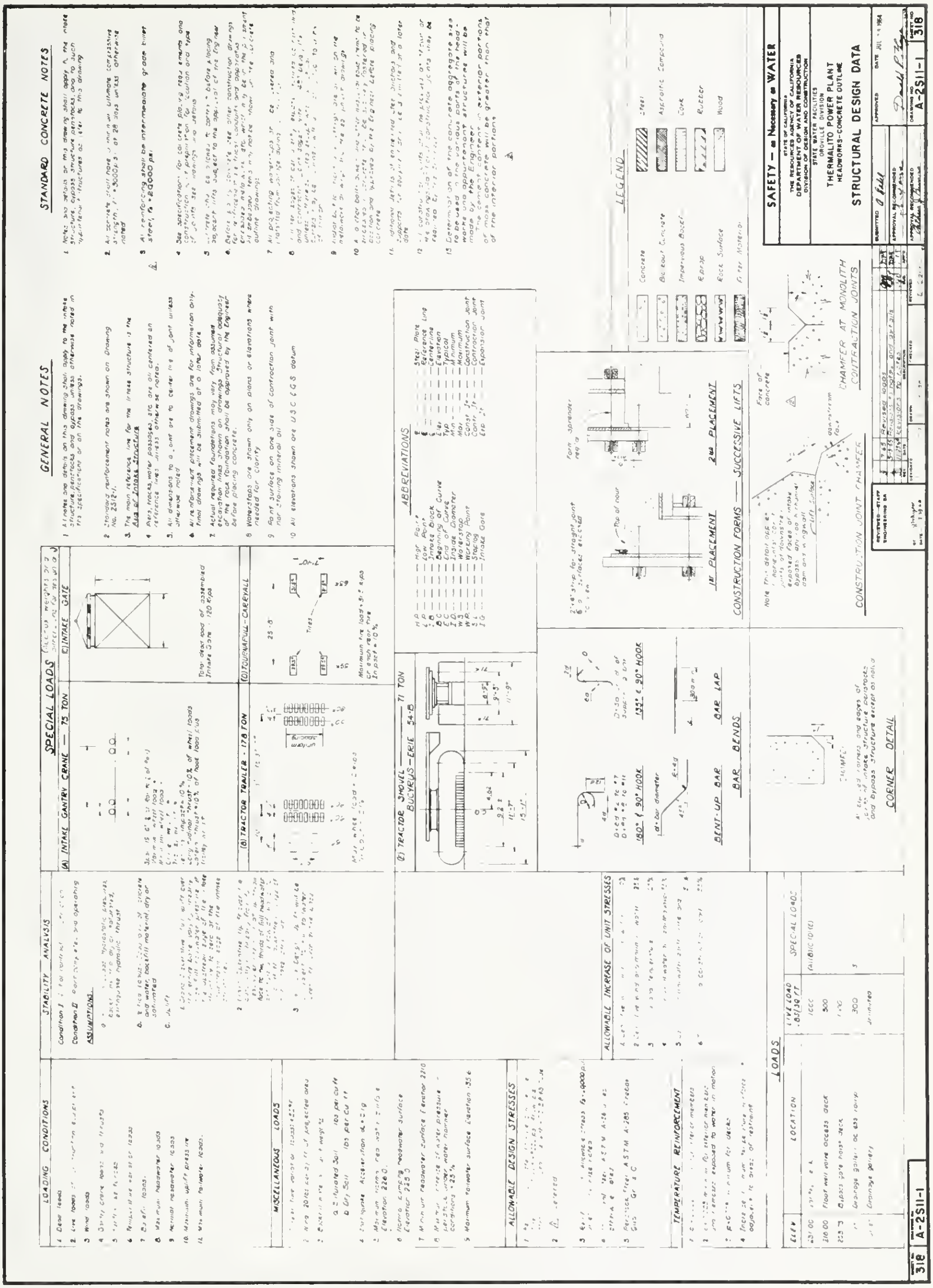

Figure 210. Headworks—Structural Design Data

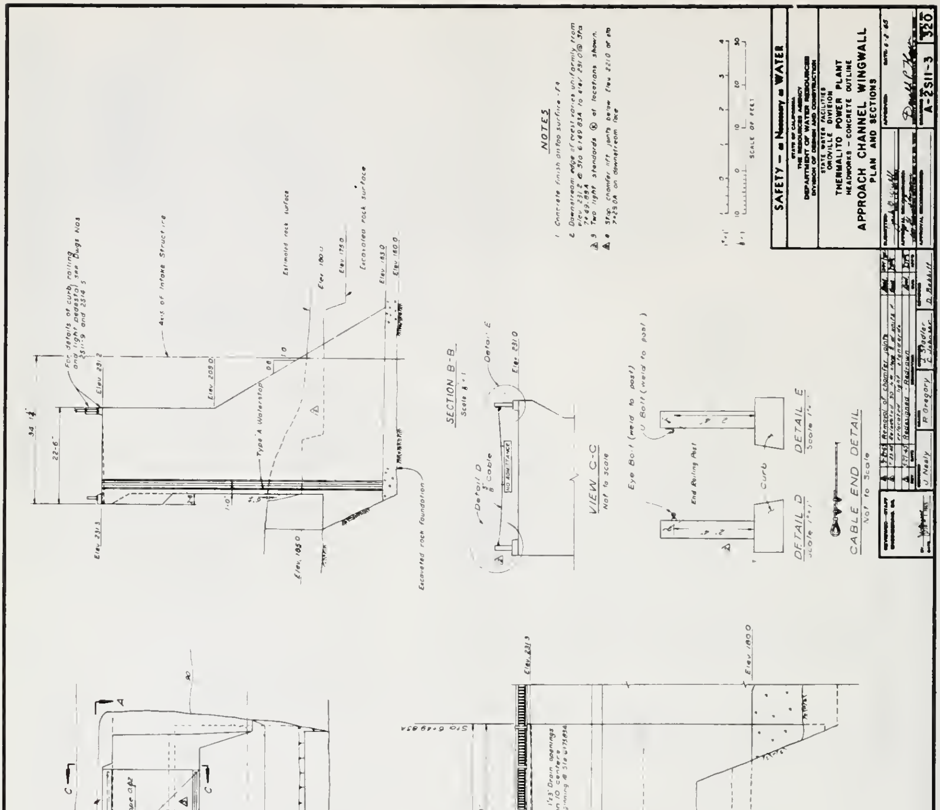

Figure 211. Approach Channel Wingwall—Plan and Sections

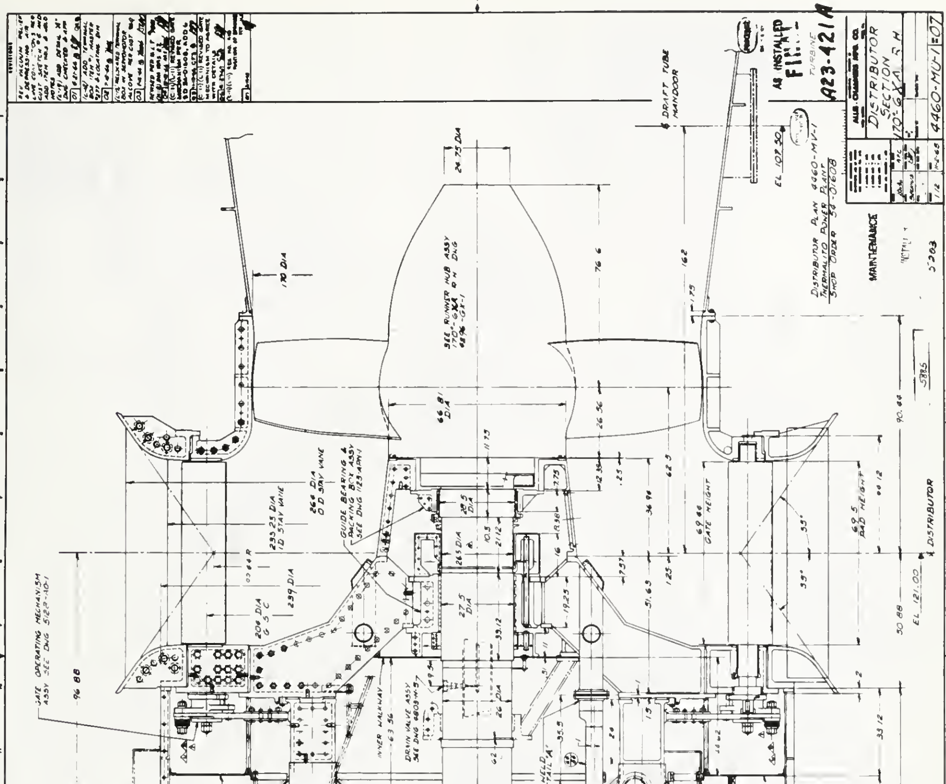

Figure 212. Koplan Turbine—Distributor Section

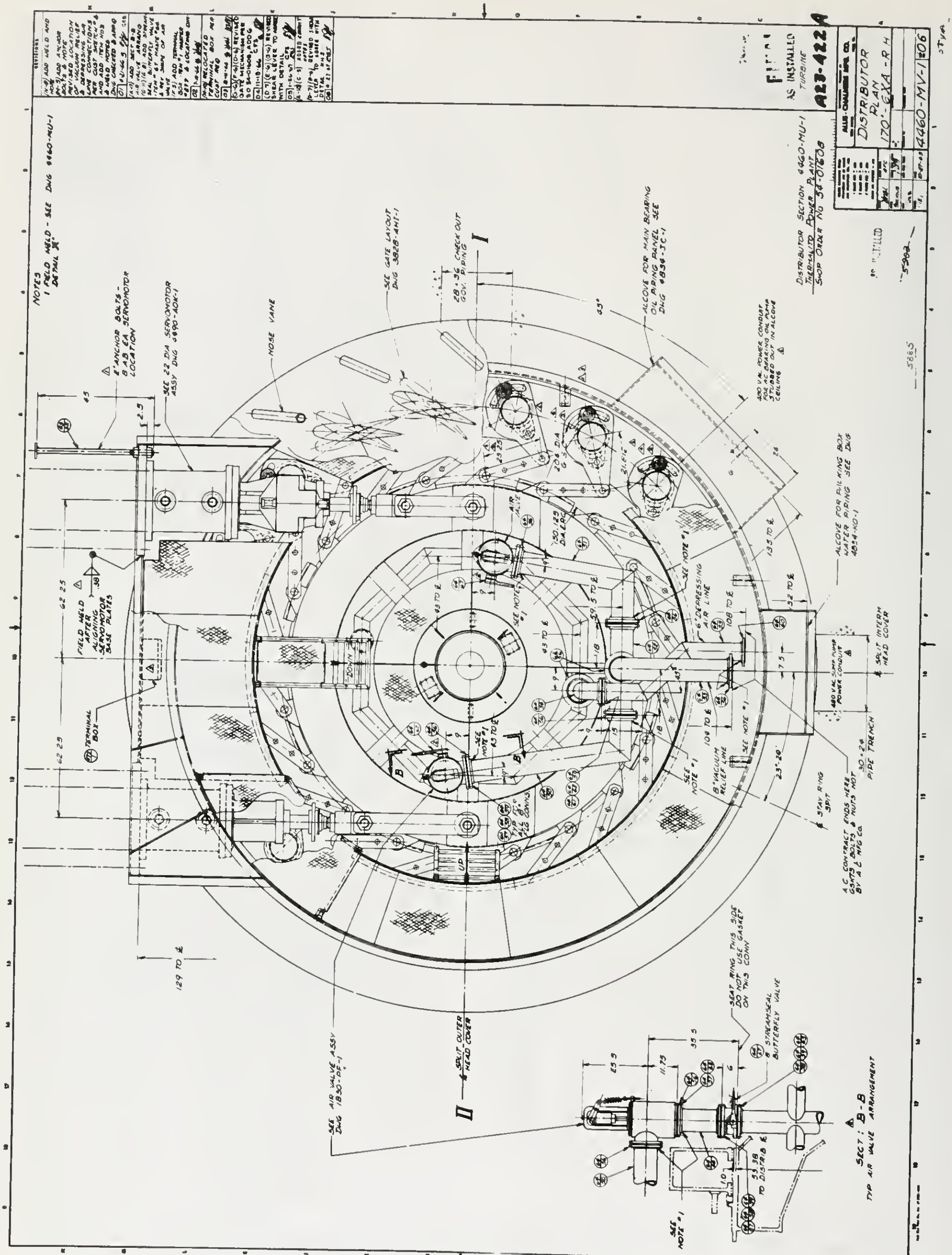

Figure 213. Kaplan Turbine—Distributor Plon

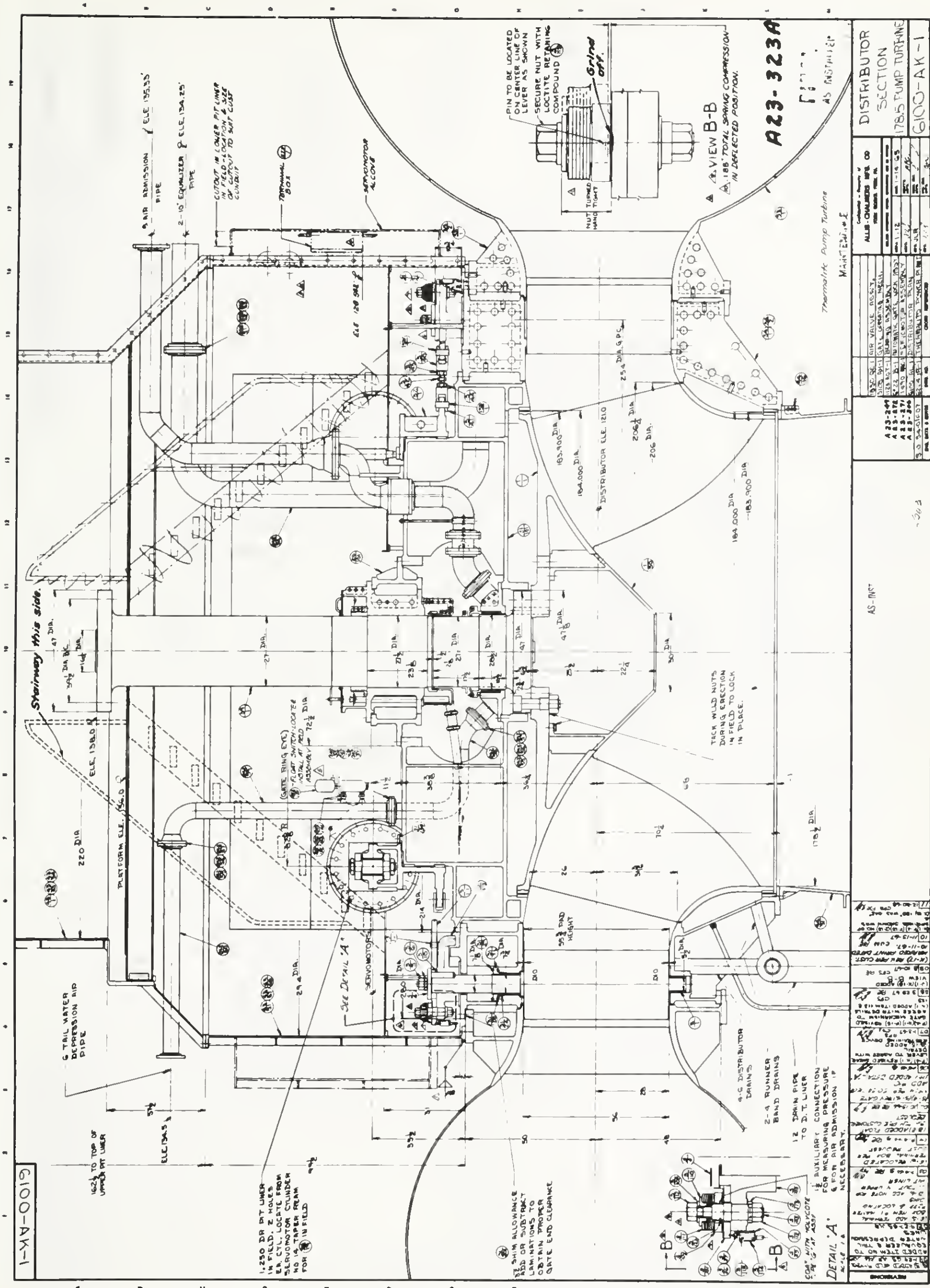

Figure 214. Pump-Turbine—Distributor Section

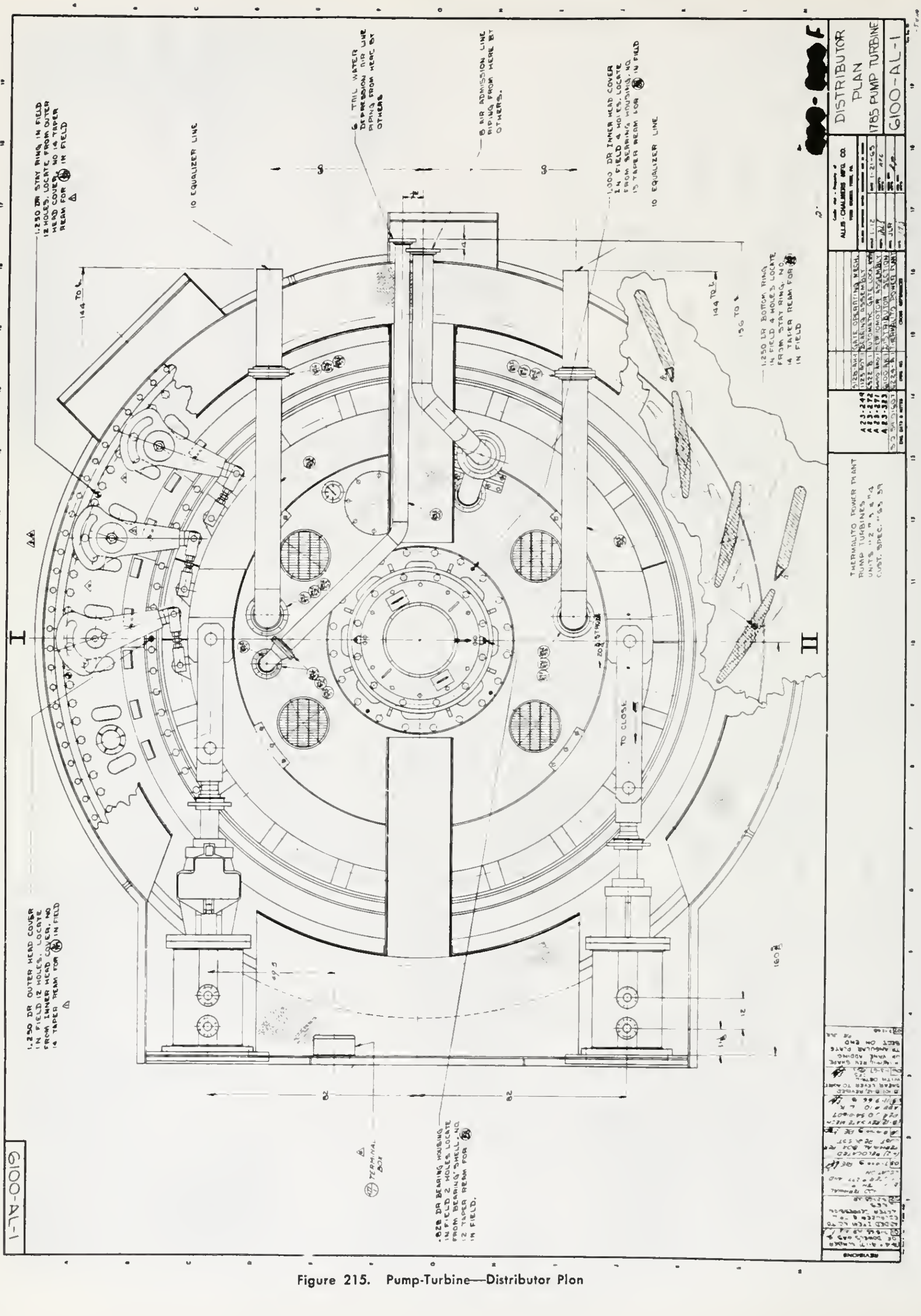

Figure 215. Pump-Turbine—Distributor Plon

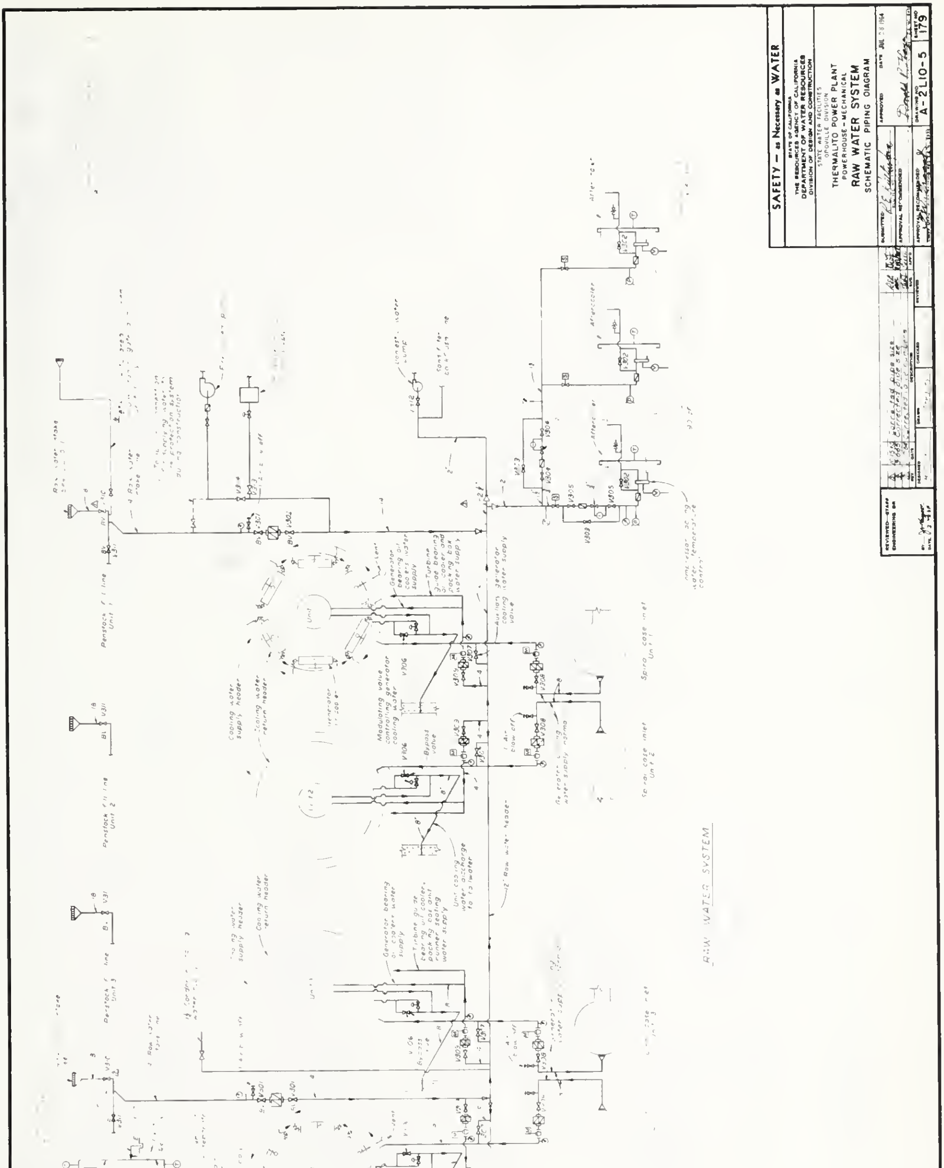

Figure 216. Raw Water System

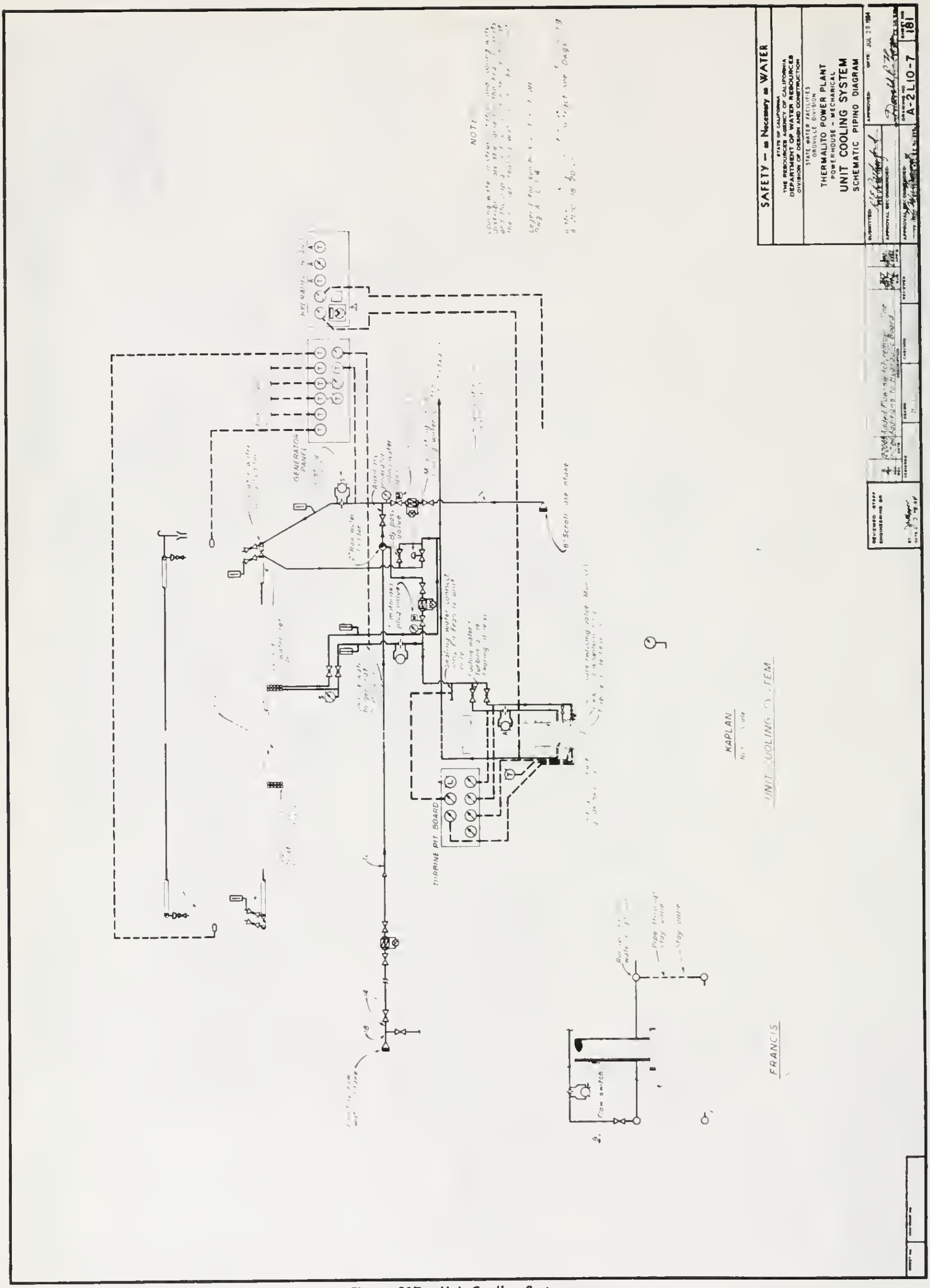

Figure 217. Unit Cooling System

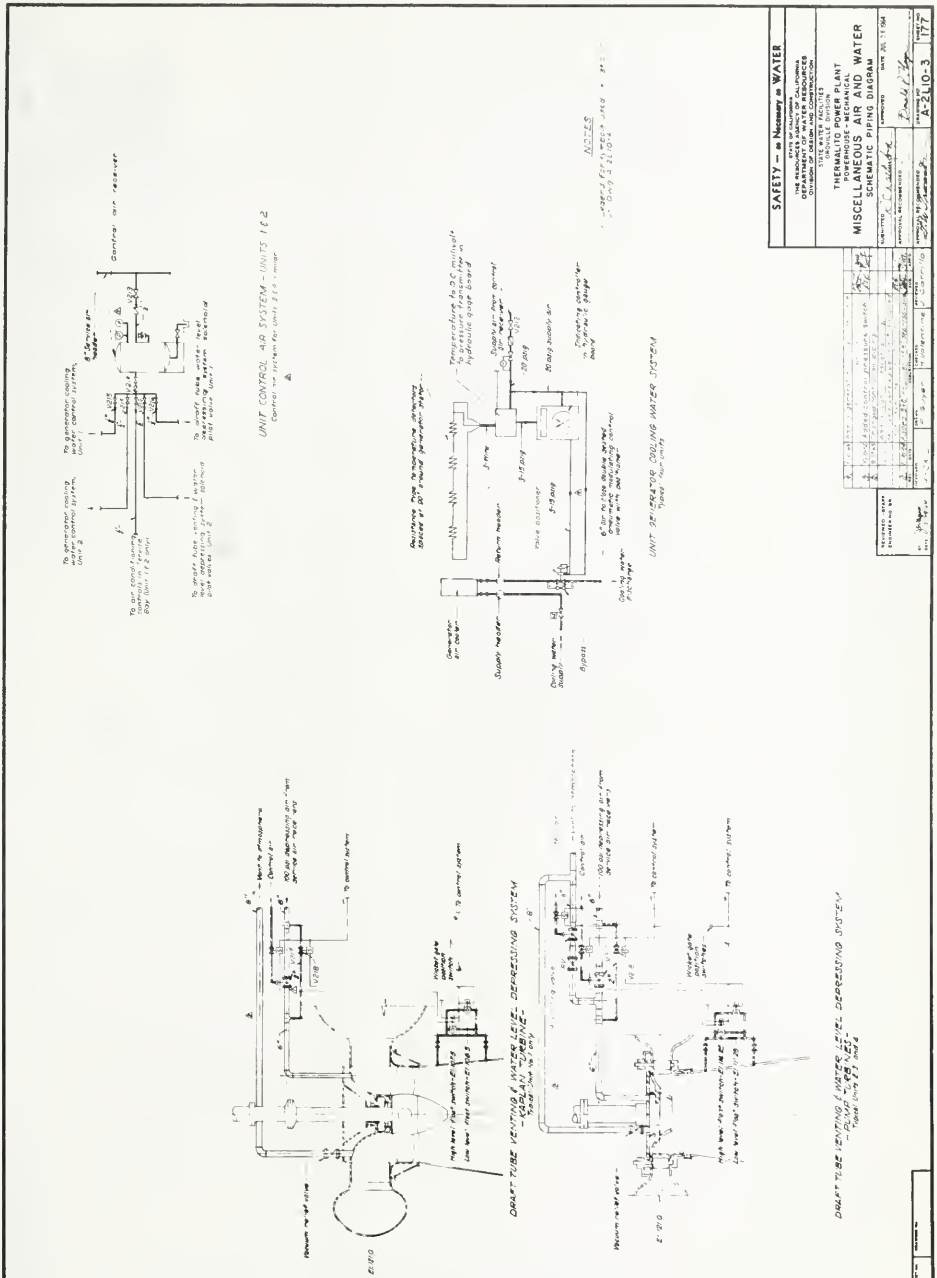

Figure 218. Miscellaneous Air and Water

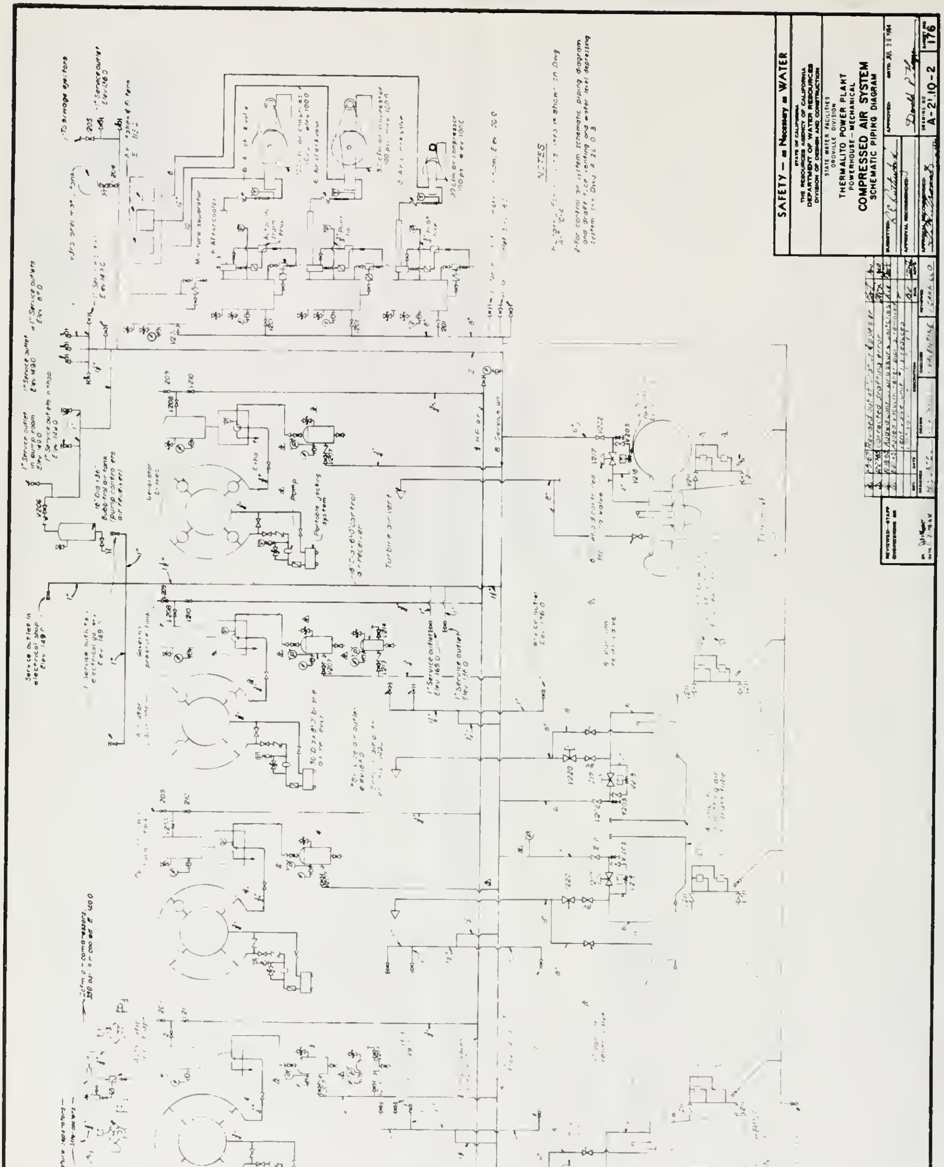

Figure 219. Compressed Air System

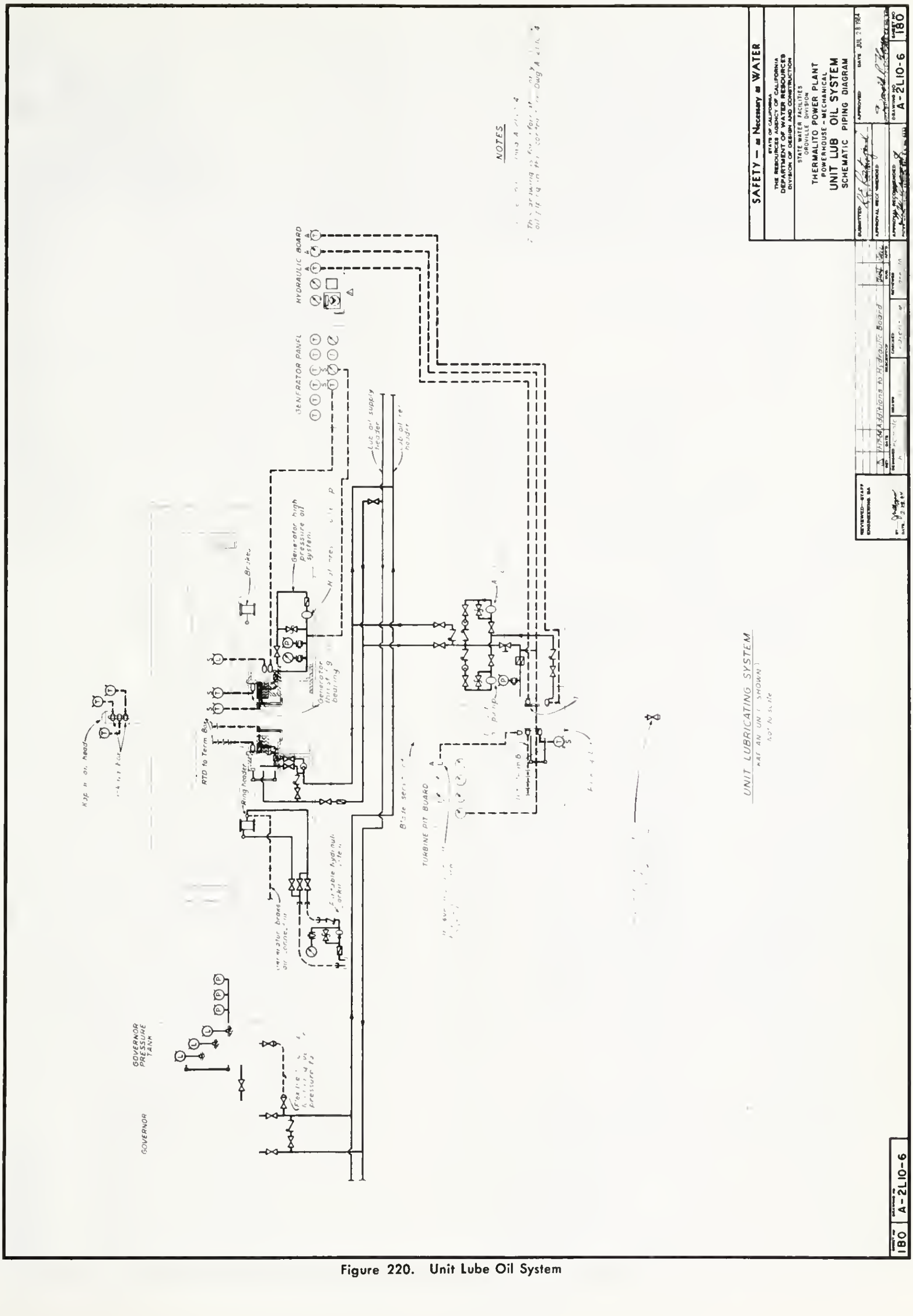

Figure 220. Unit Lube Oil System

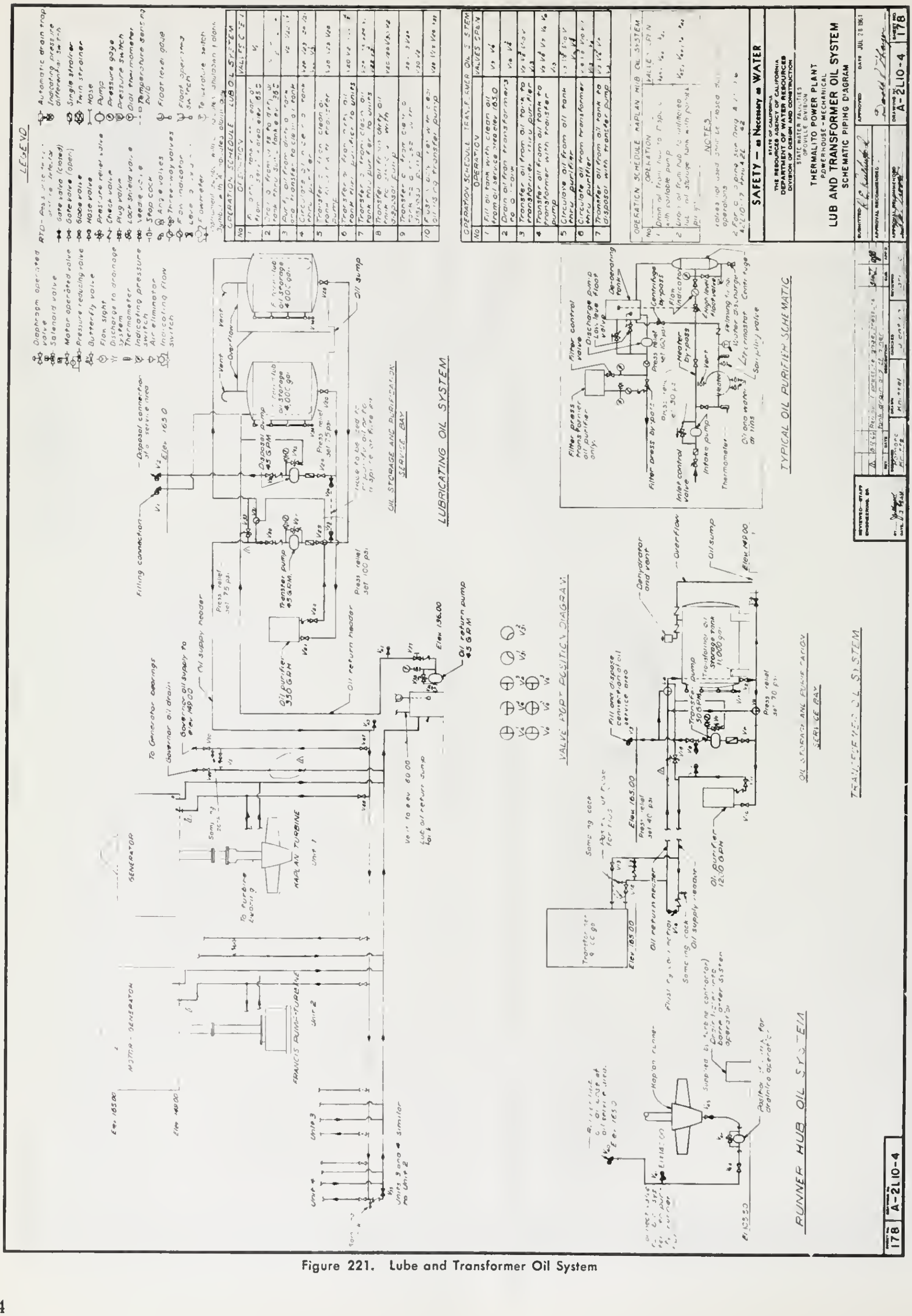

Figure 221. Lube and Transformer Oil System

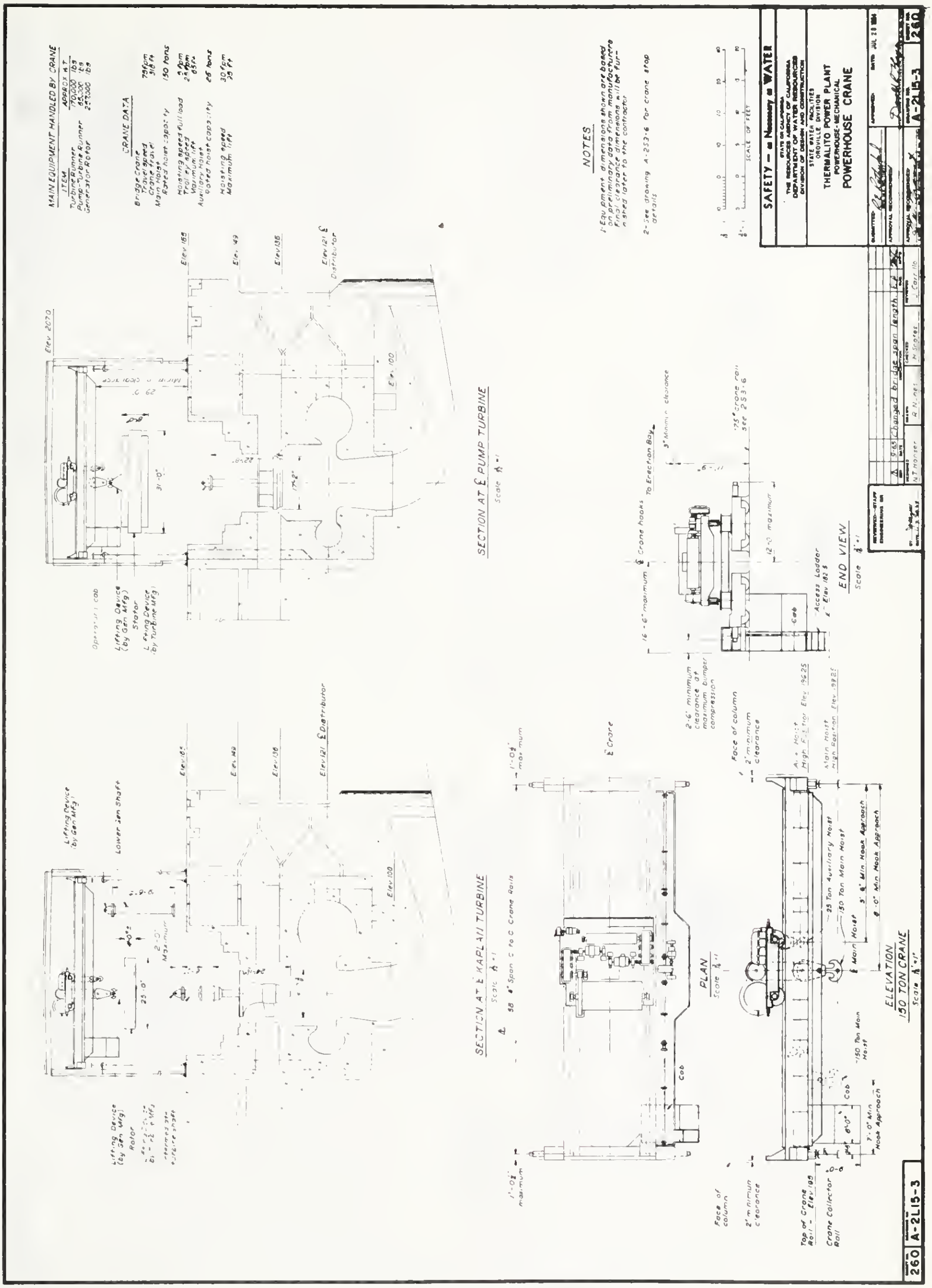

Figure 222. Powerhouse Crane

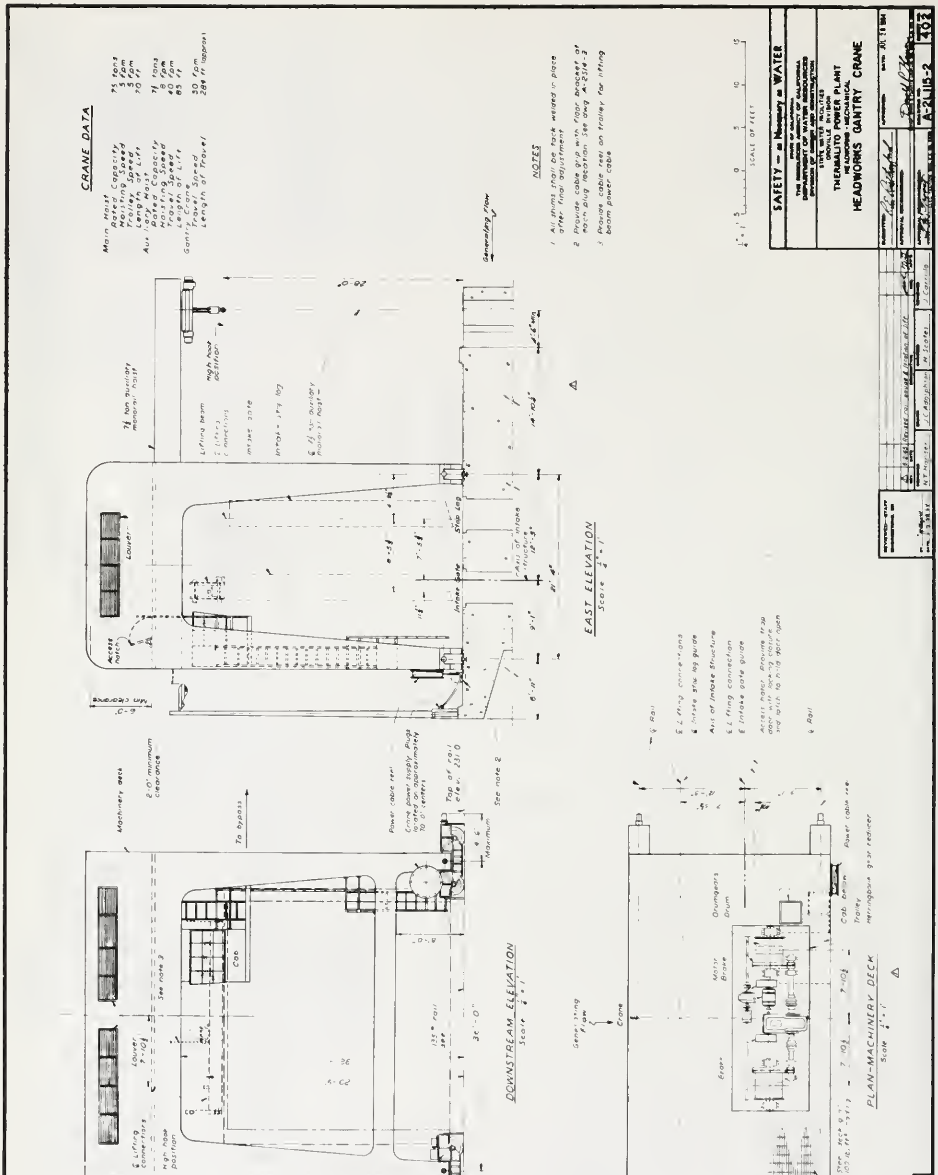

Figure 223. Headworks Gantry Crane

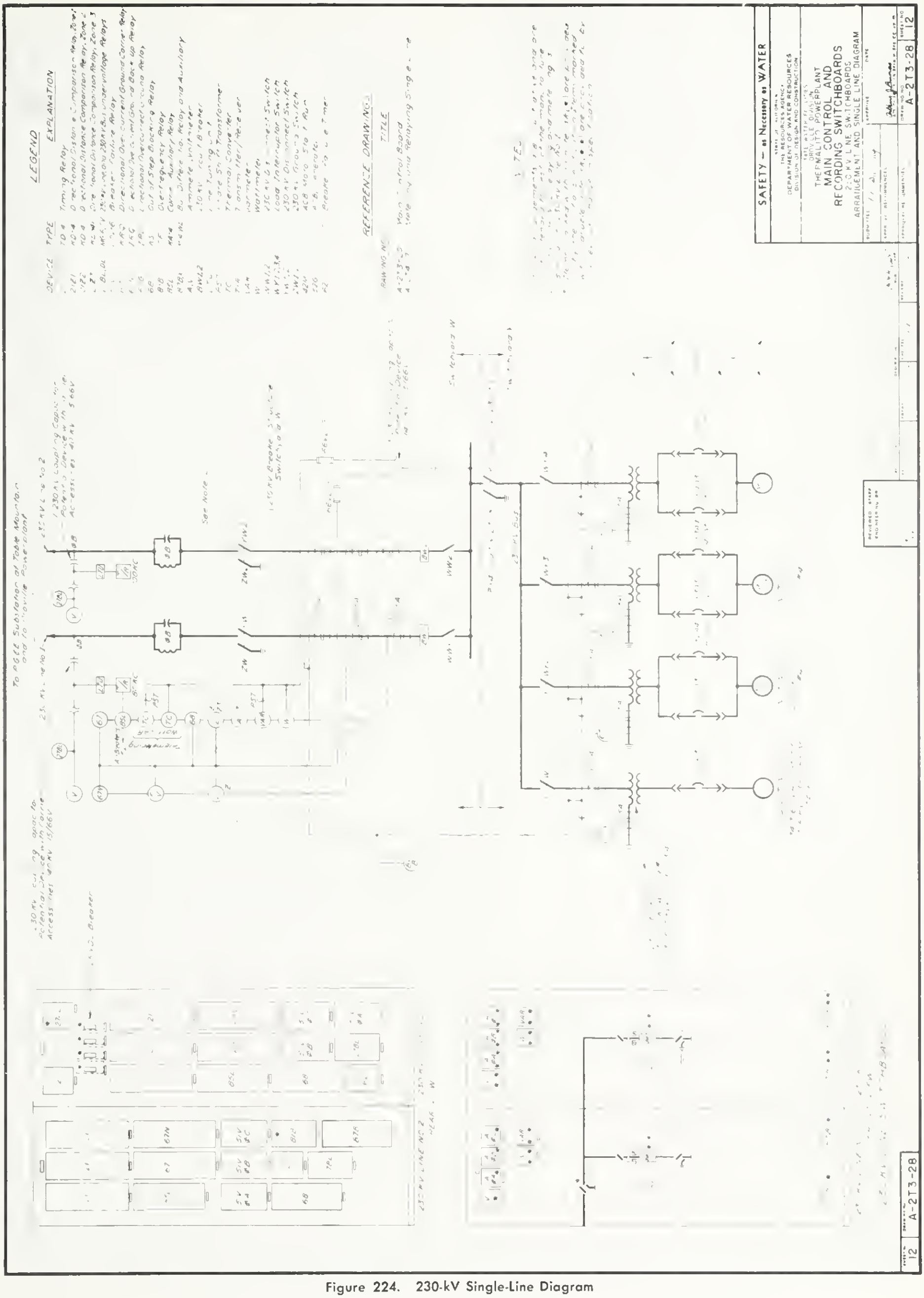

Figure 224. 230-kV Single-Line Diagram

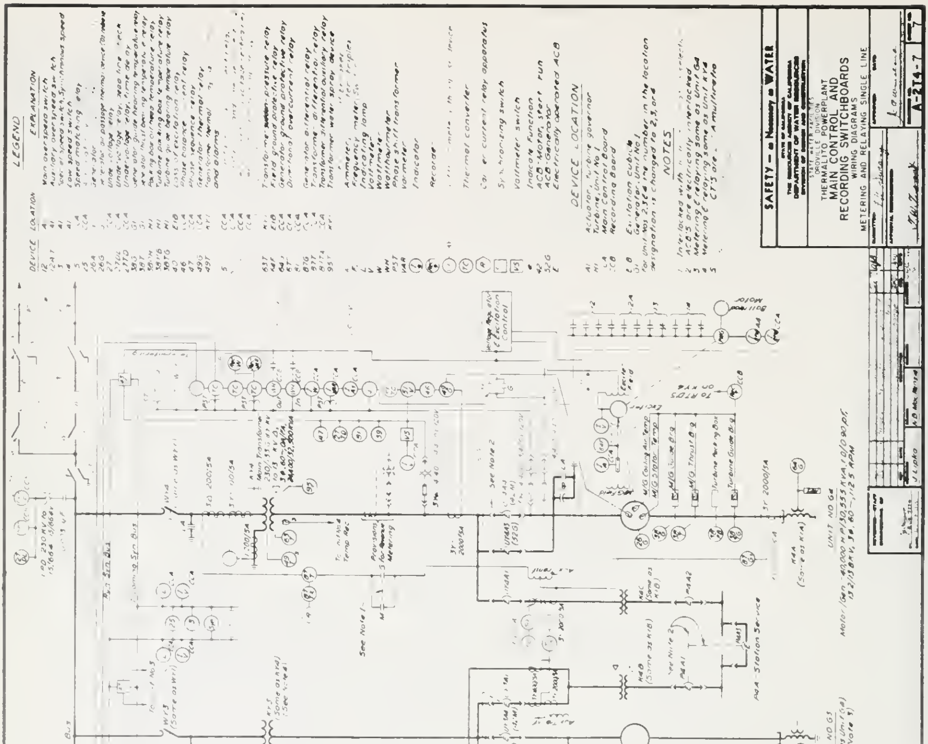

Figure 225. Metering and Relaying Single-Line Diagram

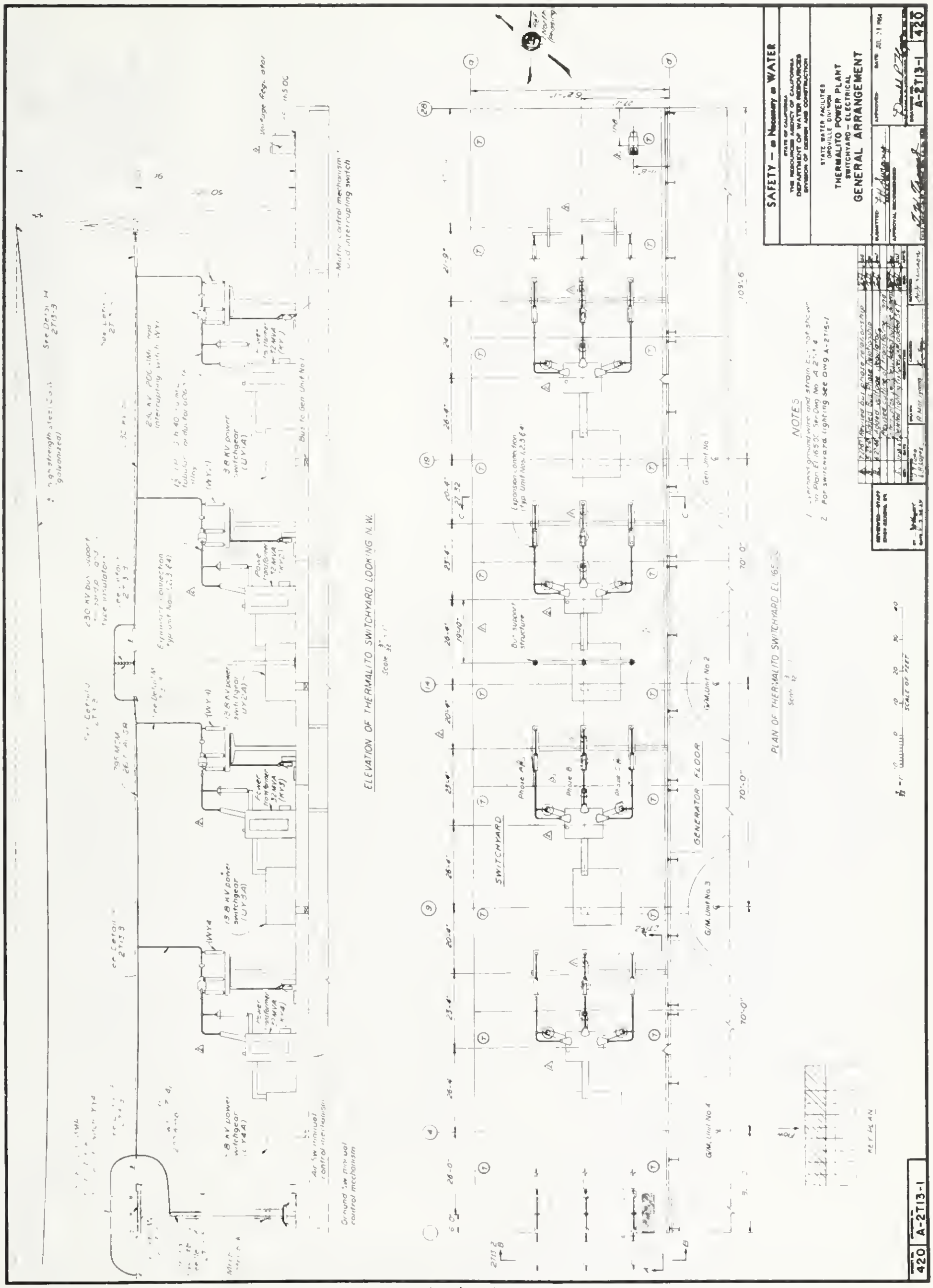

Figure 226. Switchyard Arrangement

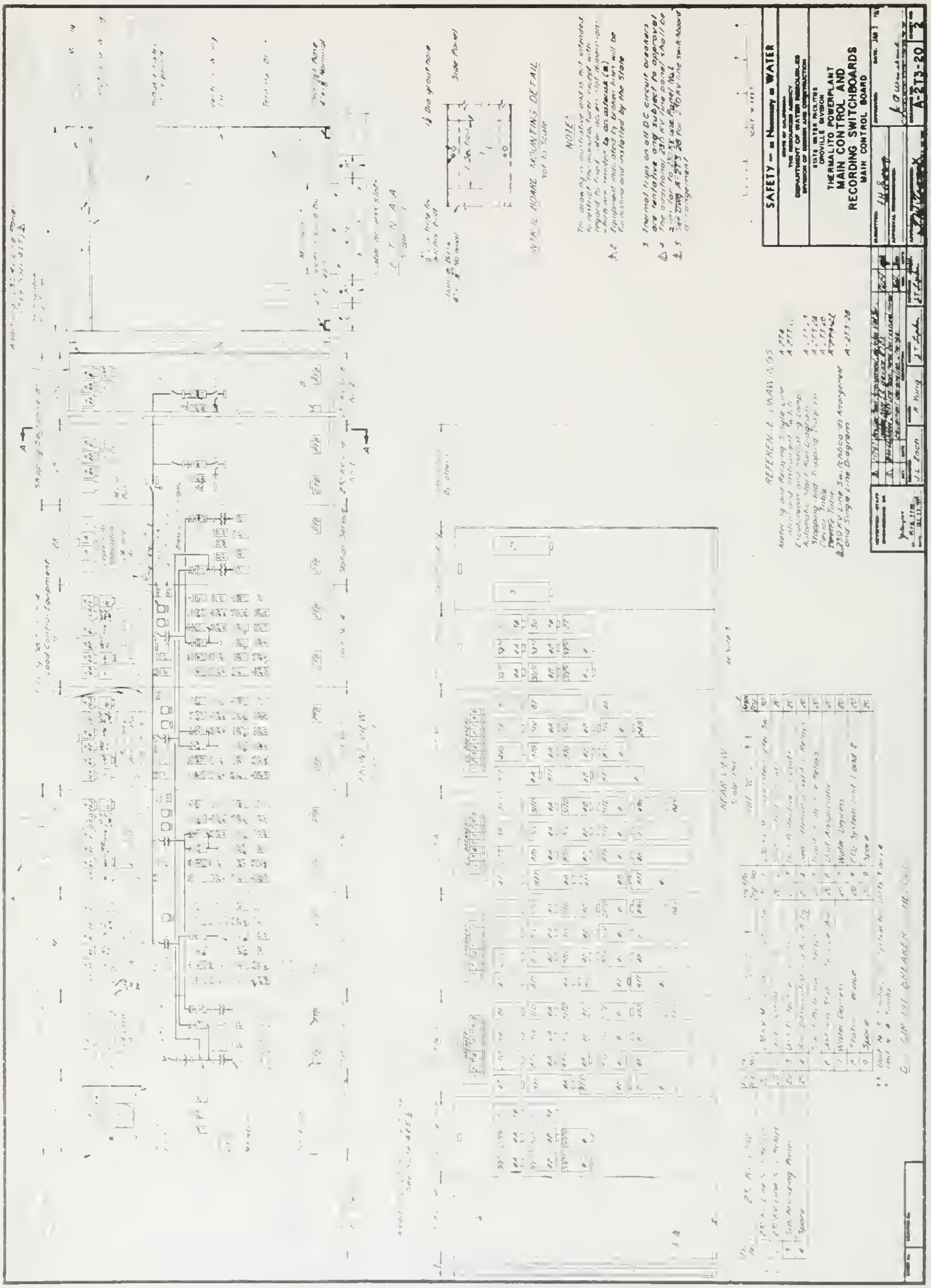

Figure 227. Switchboards

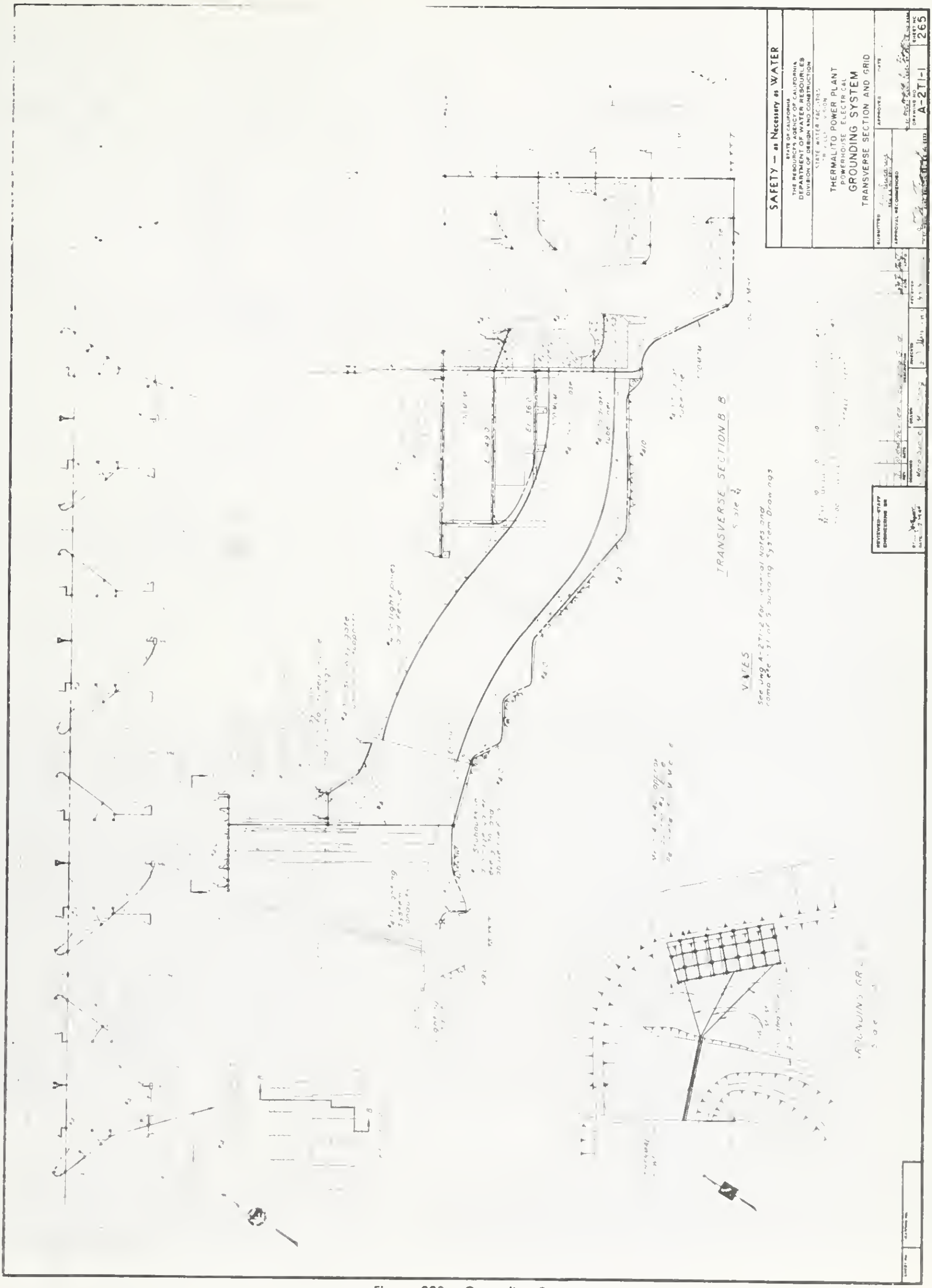

Figure 228. Grounding System

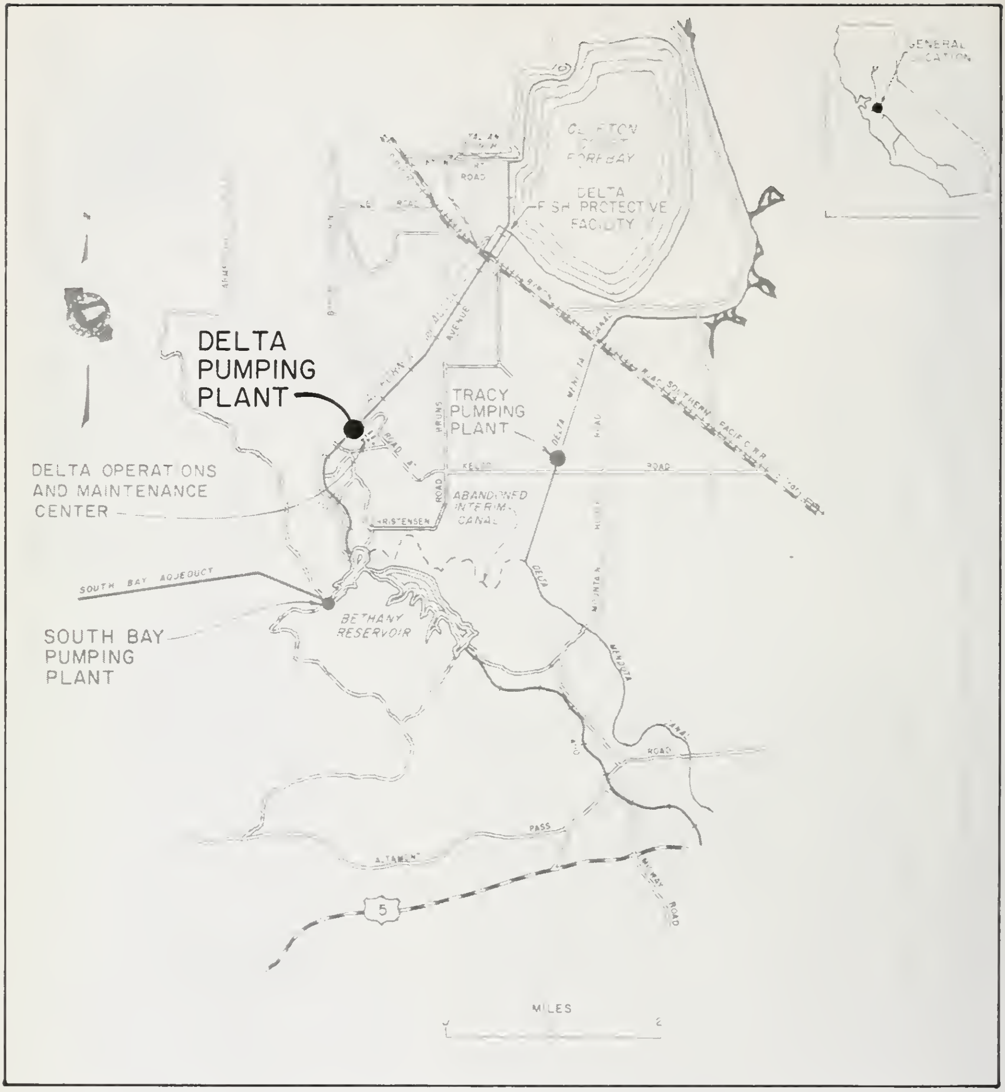

Figure 229. Location Map—Delta Pumping Plant

CHAPTER IV. DELTA PUMPING PLANT

General

Location

Delta Pumping Plant is located near the beginning of the California Aqueduct. It is approximately 12 miles northwest of Tracy, California, close to the Contra Costa-Alameda County Line (Figures 229 and 230).

Purpose

This plant provides the initial lift, 244 feet, and starts the water flowing south in the California Aqueduct of the State Water Project. An open canal transports the water to the plant from Clifton Court Forebay. Project water is presently conveyed to the Forebay through the Sacramento-San Joaquin River Delta channels and ultimately will be conveyed through the Peripheral Canal. From the plant, water flows into Bethany Reservoir, from which water for the South Bay Aqueduct is diverted. The major portion of flow continues south by gravity in the California Aqueduct to O'Neill Forebay.

Figure 230. Aerial View—Delta Pumping Plant

Description

The plant structure consists of a substructure of reinforced concrete and superstructure of structural steel with precast, concrete, wall panels and a composition roof (Figure 231). This plant will ultimately house 11 units. Seven units are presently installed: two 350 cubic-feet-per-second (cfs) units with a 11,250-horsepower (hp) rating at 400 rpm and 249-foot head, and five 1,067-cfs units with a 34,500-hp rating at 225 rpm and 249-foot head. Four additional units are scheduled for future installation, which will bring the total plant capacity to 10,300 cfs with a 333,000-rated motor horsepower. Overall plant dimensions, including the adjacent gate storage structure, are 504 feet - 5 inches long, 98 feet - 2 inches wide, and 109 feet high. The capacity of the plant bridge crane is 100 tons.

Representative drawings are included at the end of this chapter.

Architectural Design

Delta Pumping Plant was the first major plant to be designed for the California Aqueduct, and the architectural concepts developed for this complex were the basis for the architectural motif that was established as a guide to the architecture for the remainder of the State Water Project (see Volume VI of this bulletin).

Geology

Areal Geology

The plant site is on the east flank of the Altamont anticline of the Diablo Range, a mountain range that consists mainly of sedimentary rock folded into northwest-trending anticlines and synclines. The sedimentary rocks are indurated shale, sandstone, siltstone, and claystone of the Tulare, Byron, Neroly, Tesla, and Panoche formations. The area is covered by quaternary alluvial soils which extend below invert in some areas of the intake channel.

Site Geology

The pumping plant foundation is firm, unweathered, Panoche formation sandstone with interbedded shale. During excavation of the Panoche formation, the hard brittle material broke loose in large chunks leaving numerous depressions below final grade. In addition, the shale was susceptible to excessive airslaking. The finished excavation was covered with gunite to preserve the shale and expedite cleanup.

The discharge line, water tank, and outlet structure were all founded on compact Panoche formation. Except for a shear zone that crosses the discharge lines, no defects were noted which would influence the integrity of the structure. The unstable portion of the

Figure 231. Interior View of Motor Floor

discharge line excavation associated with the shear was resloped. After this portion of the cut was resloped, several seeps developed along the trace of the shear. These seeps were corrected when covered by the discharge line backfill.

Geologic Exploration

Exploration consisted of mapping, rotary and auger drilling, dozer trenching, geophysical surveys, and hydrogeologic studies.

Instrumentation

Exploration data indicated possible foundation rebound. Gauges were installed prior to construction, and a maximum 0.3 foot of rebound was recorded. A strong-motion accelerograph was installed in the plant to record seismic events.

Seismicity

The plant is located in a seismically active region. Major faults in the area include the Calaveras 27 miles west, the Hayward 32 miles west, and the San Andreas 47 miles west.

Civil Features

Preliminary Studies

Preliminary studies incorporated the siting of the Pumping Plant and the alignment of the California Aqueduct in the vicinity of the plant. Plant location was determined by balancing the cost of excavation for the intake channel and pumping plant bowl with the cost of discharge lines.

Special operational studies were made for the Aqueduct. It was concluded that pumping plants should provide peaking capability during the period of increasing demand for water delivery by the California Aqueduct. The operation of the Aqueduct was based on the "controlled volume concept" which requires that the volume and flow of water in the various reaches of the Aqueduct must be controlled within prescribed limitations. This concept was selected in preference to the use of regulating storage facilities along the Aqueduct (see Volume V of this bulletin). Selection and operation of pumps at various pumping plants was guided primarily by this concept of volume control.

Site Development

Site development began in 1963 with the construction of a 3-mile channel to the plant site from Italian Slough (prior to the construction of Clifton Court Forebay). The development also included the bowl excavation for the plant and discharge lines, a visitor overlook, rough grading for the switchyard, and a 1.4-mile access road connecting the plant to the junction of Bruns Avenue and Kelso Road. The site development for the plant was coordinated with the construction of the Delta Operations and Maintenance facilities, which are located just south of the plant bowl excavation. The plant completion contract included installation of drainage facilities and paving about the plant.

Plant Structure

The plant structure was constructed under two contracts. The initial contract, which began in 1964, included construction of the base and exterior walls of the concrete substructure and the steel superstructure. The completion contract for the plant began in 1966 and was finished in 1969. This contract included construction of the interior walls and floors, installation of seven pumps and motors, and installation of auxiliary plant equipment. This work is discussed further under the construction section of this chapter.

The reinforced-concrete substructure is divided by five transverse expansion joints to form five structurally independent unit bays and a service bay. These joints are keyed to prevent transverse or vertical differential movement between bays with no restraint of movement in the longitudinal direction. The base of the foundation for the service bay is at elevation feet, and for the unit blocks it is at elevation feet. There are four primary floor levels in the substructure located at elevations—22.0, —12.0, 2.0, and 14.5 feet. This pumping plant is constructed with 90-degree suction elbows with inverts set at elevation −28 feet for Units Nos. 3 through 11 and elevation −23 feet for Units Nos. 1 and 2.

The superstructure is also divided by expansion joints, matching those in the substructure. Rigid steel frames with stepped columns to support the 100-ton bridge crane are anchored to the top floor at elevation 14.5 feet. The superstructure is enclosed with precast, concrete, wall panels and a composition roof.

Earthquake design of this plant complied with Uniform Building Code requirements. Earthquake design criteria outlined in Chapter I of this volume were not yet available at the time of final design.

Foundation design considerations governed the orientation of the plant with respect to the alignment of the intake channel and the discharge lines. The longitudinal axis of the plant was rotated 10 degrees in a clockwise direction to align the structure with the strike of a sandstone formation underlying the plant foundation. This rotation was compatible with a skew arrangement of pumping units which resulted in a reduction of overall space requirement and of concrete quantities.

Waterways

Intake Facilities. Intake facilities include the intake channel transition, trashracks, bulkhead gates, and suction tubes.

The intake channel bottom width was increased as it approached the plant structure to form a small forebay. Warped, counterforted, retaining walls retain the side slopes of the transition. The bottoms of the forebay and intake channel are unlined.

Vertical trashracks were installed at the face of the plant structure. They were constructed in panels to facilitate their handling and were designed to prevent debris larger than 3 inches from entering the pumps.

Structural-steel bulkhead gates are provided for the units currently installed. For future units, the bulkhead gates are constructed of lightweight reinforced concrete which will be replaced by steel gates after the units are installed.

Trashracks and bulkhead gates are handled by a 10-ton gantry crane that traverses the front deck of the plant.

The upstream portion of the suction elbows is formed in the structure concrete, while the portion immediately below the pump impeller is steel-lined. This is one of the few plants on the California Aqueduct that has 90-degree suction elbows because there was no need for deep foundation excavation or keying of the plant foundation to provide stability against sliding.

Pump Discharge Lines. Pump discharge lines include articulations, manifolds, buried steel pipe, protective coatings, and the outlet structure.

The pumps lift water into the California Aqueduct through five discharge lines. Flow from pumps 1, 2, and 3 is manifolded into a 13½-foot-diameter, buried, steel pipe. Flow from the succeeding pairs of pumps 4–5 and 6–7 is combined into two 15-foot-diameter steel pipes. Future pumps 8–9 and 10–11 will discharge into the third and fourth 15-foot-diameter pipes.

This combination of size and number of discharge lines was determined from an economic study involving flow demands, power costs, and pipe material and installation costs.

Flow capacity for the discharge lines is 1,767 cfs for the 13½-foot pipe and 2,134 cfs for each of the four 15-foot pipes, for a total of 10,300 cfs.

Approximate lengths of discharge lines from the upstream side of the manifolds to the start of the outlet structure are 1,040 feet for the 13½-foot pipe and 1,065, 1,081, 1,103, and 1,130 feet for the four 15-foot pipes.

From the manifold, about 305 feet downstream from the Pumping Plant, the five discharge lines converge to 25-foot centerlines. At this point, the four outboard discharge lines are encased by separate reinforced-concrete anchor blocks to resist thrust resulting from change in flow direction. From the anchor blocks, the discharge lines extend parallel up a 21% slope for about 775 feet, at which point the four outside discharge lines converge to a 17-foot centerline spacing. The discharge lines are parallel for 8 feet to the junction with the outlet structure transition. Within the last 13 feet, the 13½-foot pipe is enlarged to a 15-foot diameter.

Articulations. Articulations for discharge lines are housed within the coupling chambers and consist of steel tapers from the pump discharge valves to a short section of pipe, two sleeve couplings with an intermediate make-up spool of pipe, and a short section of pipe into the upstream wall of the chambers.

The make-up spool, which is suspended by two sleeve couplings, is 2 inches shorter than the opening. This arrangement provides articulation for the discharge lines in the event of differential settlement between the Pumping Plant and the manifold structure. The maximum rotation provided for is 2 degrees from normal, which permits a maximum differential settlement of approximately 2 inches. The make-up section also serves as a roll-out section for access to the discharge lines from the pumping plant end.

Manifolds. The manifolds extend from the upstream walls of the sleeve-coupling chambers to the junction with the 13½-foot and 15-foot discharge lines. The first manifold combines the two 7-foot discharge lines of the 350-cfs pumps with the 10½-foot discharge line from the first 1,067-cfs pump. Each of the remaining four manifolds combine the 10½-foot discharge lines from two of the 1,067-cfs pumps. Pipe intersections are at 45 degrees. All manifold pipes are encased in reinforced concrete to strengthen anchorage and resist external loads. Before being encased in concrete, steel manifold pipes were bulkheaded and hydraulically tested to a pressure 1.5 times the design working pressure. Structural steel supports, provided to resist thrust and water loads during the test, were left in place and encased in the manifold concrete.

Buried Steel Pipe. Three types of pipes, monolithic concrete, prestressed concrete, and steel, were advertised as alternatives in the contract for construction of Delta Pumping Plant and discharge lines. Steel pipe was included in the lowest overall bid for the contract and was therefore installed. However, in one bid, monolithic concrete pipe was priced lower than the steel pipe of the low bid.

Discharge lines are continuous, all welded, ASTM A441 steel. Wall thickness varied according to internal pressure and external loading conditions which required thicker pipe walls at the manifolds. At the contractor's suggestion, pipe with uniform thicknesses of $\frac{7}{16}$ of an inch for 13½-foot pipe and ½ inch for 15-foot pipes was installed with no increase in cost.

Nine-inch by three-quarter-inch stiffener rings were welded on the pipes to resist water pressure and external load and to facilitate handling during fabrication, delivery, and installation. Rings are spaced at 9-foot - 11-inch intervals except under roadway fill at the manifolds and outlet structure where they are on a nominal 4-foot - 11½-inch spacing.

Acoustical velocity flow measuring devices are located approximately 177 feet upstream of the outlet structure. Eight-inch and one-and-one-half-inch pipes also were installed to measure flow by the salt-injection method. One set of leading edge flowmeter transducers was installed in each discharge line to measure flow by transmitting acoustic waves through water in the pipe. This acoustical system did not produce acceptable results for all flow conditions, partly because the transducers were buried in the backfill and were inaccessible for maintenance and adjustment. In the spring of 1974, new acoustical devices (four pairs per pipe) were installed in accessible concrete vaults adjacent to the original devices.

The discharge lines are bedded from 15 inches below invert up to a 120-degree bedding angle in consolidated, selected, pervious backfill. Backfill above the consolidated material to within 6 inches of the top of the discharge line is compacted selected material, and the top 3 feet - 6 inches is common backfill.

The discharge lines are joined to the outlet structure by a 25-foot-long reinforced-concrete transition, circular to 15-foot square.

Protective Coatings. Steel pipe in the manifolds and discharge lines is lined with vinyl paint and coated with coal-tar enamel for protection against corrosion.

Outlet Structure. A radial-gated outlet structure prevents water in the California Aqueduct from flowing back into the discharge lines during emergencies, such as malfunction of discharge valves and failure of discharge lines, or during inspection and maintenance of the discharge lines.

The reinforced-concrete outlet structure consists of five bays and an outlet transition to the trapezoidal concrete-lined aqueduct. The radial gate bay is 88 feet wide, 57 feet long, and 24 feet deep. It contains five 15-foot-wide by 17-foot-high radial gates with hoists, motors, and controls on a 12-foot-wide deck.

An 80-foot-long reinforced-concrete structure, the invert of which drops from elevation 227.76 feet at the gate bays to elevation 213.40 feet at the Aqueduct, forms a transition from the outlet structure to the Aqueduct. Walls of the transition change from vertical at the outlet structure to $1\frac{1}{2}$:1 at the Aqueduct. The walls are counterforted for 48 feet downstream from the structure and are supported on earth cut slopes for the remainder of the distance.

Cutoff walls extend 4 feet below invert at the end of the gate bays and at the junction of the outlet transition and the aqueduct lining.

A 40-foot-wide roadway crosses the top of the outlet structure and the upper section of the discharge lines.

Mechanical Features

General

The present mechanical installation includes seven pumps, seven pump discharge valves, two equipment-handling cranes, and auxiliary equipment. The Pumping Plant has provisions for four additional units and their auxiliary equipment.

Chapter I of this volume contains information on the mechanical equipment for the Delta Pumping Plant which is common to other plants in the State Water Project. Information and descriptions which are unique to this plant are included in the following:

Equipment Ratings

Pumps

Manufacturer: Newport News Shipbuilding and Dry Dock Company

Type: Vertical-shaft, single-stage, centrifugal

Pumps Nos. 1 and 2

Discharge, each:	350 cfs
Total Head:	249 feet
Speed:	400 rpm
Guaranteed Efficiency:	92.7%
Minimum Submergence at Pump Centerline:	3 feet

Pumps Nos. 3, 4, 5, 6, and 7

Discharge, each:	1,067 cfs
Total Head:	249 feet
Speed:	225 rpm
Guaranteed Efficiency:	93.3%
Minimum Submergence at Pump Centerline:	3 feet

Future Units Nos. 8, 9, 10, and 11 will have a rated capacity of 1,067 cfs each at 249 feet of total head.

Pump Discharge Valves

Manufacturer: Westinghouse Electric Corporation

Type and Size

Units Nos. 1 and 2: 54-inch, double-seated, spherical box after reset

Units Nos. 3 through 7: 84-inch, double-seated, spherical box after reset

Present plans call for installation of 84-inch, double-seated, spherical valves on Units Nos. 8 through 11.

Cranes

100-Ton Bridge Crane

Manufacturer: American Crane and Hoist Corporation

Type: Overhead, traveling, bridge

10-Ton Gantry Crane

Manufacturer: Crane Hoist Engineering and Manufacturing Company

Type: Outdoor, traveling, gantry

Figure 232. Preparing Pump Casing for Hydrostatic Test

Pumps

The pumps are vertical-shaft, single-stage, diffuser casing, centrifugal type, directly connected to vertical-shaft synchronous motors (Figure 232). All pumps rotate counterclockwise as viewed from the motor end.

The pump casings are embedded in the concrete substructure of the plant. The pump impeller, shaft, guide bearing and housing, and top casing cover are all removable from above when the motor rotor is removed (Figures 233 and 234). The hydraulic thrust and the weight of the rotating parts are carried by a thrust bearing in the motor.

The impellers have corrosion-resistant, steel, wearing rings. Removable and renewable wearing rings are located in the suction and casing covers opposite the wearing rings on the impeller crown and band. The wearing rings are made of precipitation-hardened corrosion-resistant stainless steel.

Figure 233. Machining of Pump Casing

Figure 234. Pump Impeller Before Attaching Band

Figure 235. Pump Pit and Intermediate Shaft Bearing

All pump shafts are made of forged, open-hearth, carbon steel with 6-inch-diameter axial bore. Shafts for the small units are 22-inch diameter and weigh 13,200 pounds each, while the shafts for the large units are 36-inch diameter and weigh 47,500 pounds each. A removable, corrosion-resistant, steel sleeve is secured to the shaft where it passes through a packing box.

The packing box is made of cast-steel halves. It is bolted to the casing cover and is packed with rings of 1-inch-square asbestos. A bronze lantern ring separates the rings into upper and lower sections. Packings are lubricated with filtered water.

Each pump has a guide bearing. In addition, each large unit (1,067 cfs) has an intermediate bearing located between the motor guide bearing and the pump guide bearing. The intermediate bearing was required to limit the shafts' critical speeds to safe operating conditions (Figure 235). Both pump guide and intermediate bearing shells are lined with babbitt and are lubricated by a forced feed oil system. The babbitt is grooved for better oil circulation.

All pumps were designed to be started with the casing dewatered by depressing the water level below the pump impeller with compressed air The air is admitted into the pump casing while the intake gate is open and the spherical valve is closed. After the pump motor is synchronized, the air is gradually bled off, allowing water to reenter the pump casing until it is full. When the pump discharge pressure reaches approximately 105 pounds per square inch gauge (the static head on the system), a check valve in the bypass around the main discharge valve opens. At approximately 110 pounds per square inch (psi), a pressure switch mounted on the pump casing starts the valve sequencing unit which opens the discharge valve. When the discharge valve is fully opened, the air vent is closed and normal pumping begins.

Pump Discharge Valves

A double-seat spherical valve was installed on the discharge side of each centrifugal pump. The valves are shutoffs to prevent backflow through the pump units when they are stopped and to isolate each pump from its discharge line for inspection and maintenance (Figures 236 and 237).

Each valve and its appurtenances are located in a separate valve vault at the end of the discharge extension of each pump casing. Units Nos. 1 and 2 have 54-inch-diameter valves, each weighing approximately 56,000 pounds; and Units Nos. 3 through 7 have 84-inch-diameter valves, each weighing approximately 105,000 pounds.

The operating mechanism for each valve is basically composed of an operating cylinder, piston, piston rod, operating lever, and locking device (Figure 238). The cylinder is double-acting, with the control system set up to simultaneously vent one side of the cylinder to the oil sump tank and allow oil to enter the other side under high pressure from the accumulator tank. The rate of valve movement is controlled by a metering valve on the discharge side of the cylinder.

Each valve plug is rotated by its individual hydraulic system and is pressurized by an air-over-oil accumulator. Each system, operating at a pressure of 500 psi, is capable of one opening cycle and one closing cycle, after which the system pressure reduces to 375 psi, and it must be recharged before the valve can be operated.

Each system includes an oil accumulator; oil sump tank and pumps; air compressor; directional and flow control valves; hydraulic control panel; valve control center; and necessary piping, wiring, and instruments.

The air compressor and two hydraulic oil pumps

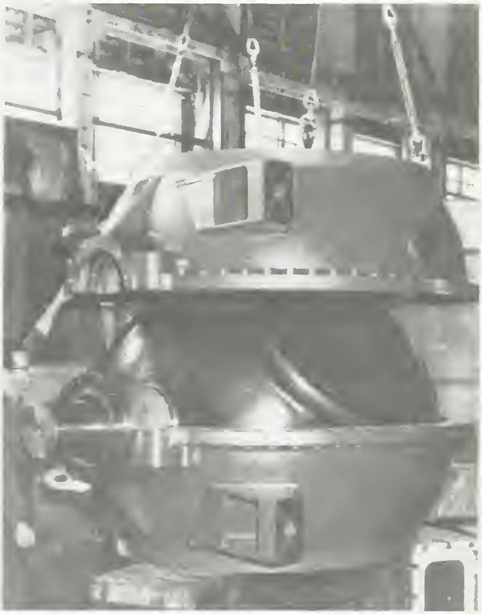

Figure 237. Shop Assembly of Spherical Valve

Figure 236. Preparing Shop-Assembled Valve for Hydrostatic Test

Figure 238. Spherical Valve Showing Operating Mechanism

supply air and hydraulic fluid respectively to the accumulator. The compressor and pumps normally are operated automatically but can be operated manually from the valve control center.

The valve seats are oil-operated and are located upstream and downstream of the transverse centerline of the valve. The seals are arranged so that either the upstream or downstream ring can be moved independently. The upstream seat is used as an operating seat, and the downstream seat is maintained in the open position and used as a shutoff valve when maintenance is required on the operating seat or on the pumps.

The pump discharge valve normally is operated only in the fully opened or closed position. The opening and closing of the valve is controlled by a mechanical-electrical sequencer using cam-operated switches and hydraulic valves. The cams are mounted on a shaft which is driven by a 125-volt direct-current motor. The motor is controlled by a reversing starter whose forward and reverse contactors are energized and deenergized by plug and seat limit switches and the cam-actuated switches previously mentioned.

Cross connections are provided between accumulators as an extra safety measure. In case of failure of one accumulator, the valve can be operated by using the hydraulic system of the second unit.

Hydraulic Transients

Surge and reverse speed control are provided by a two-speed pump-discharge-valve closure. The discharge valve opens and closes at an approximately uniform rate for normal conditions. During emergency conditions (power failure or tripping of pump motor circuit breakers), the discharge valve closes automatically to 20% of rated flow in 5 seconds and then completes the remainder of the stroke in 60 seconds. The actual closure speed was selected under operating field test conditions. Closure is adjustable from 5 to 15 seconds for the fast portion of stroke and 60 to 120 seconds for the slow portion. Studies indicated that a single-speed closure of approximately 27 seconds will provide the control needed. The valves will be converted to a single-speed closure.

Equipment Handling—Cranes

Assembly and maintenance of major pumping plant equipment, including pumps, motors, and discharge valves, is by means of a 100-ton, indoor, bridge crane (Figure 239).

The plant also has a 10-ton, outdoor, gantry crane which is used to raise, lower, and transport the intake bulkhead gates (Figure 240).

The bridge crane is an electric, cab-operated, overhead, traveling type, with a main 100-ton-capacity hook and an auxiliary 25-ton-capacity hook. A sister-

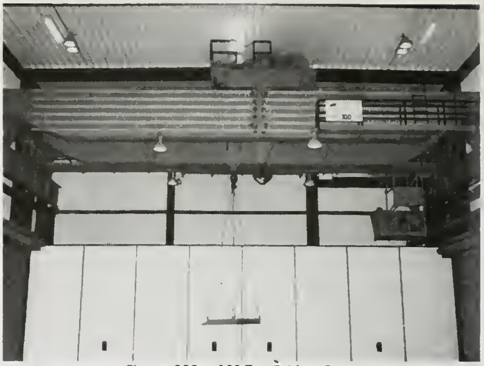

Figure 239. 100-Ton Bridge Crane

Figure 240. 10-Ton Gantry Crane

type hook, bored for a lifting pin, is provided for the main hoist.

The rated capacities and speeds of the bridge crane are:

Rated capacity, tons	100
Number of trolleys	1
Rated capacity of main hoist, tons	100
Rated capacity of auxiliary hoist, tons	25
Maximum lift, main hoist, feet—inches	73′—0″
Maximum lift, auxiliary hoist, feet—inches	73′—0″
Span, feet—inches	58′—1½″
Hook, Speeds—feet per minute (fpm)	
Main (5 step) variable	0–3
Aux. (5 step) variable	0–15
Bridge speed—fpm (5 step) variable	0–80
Trolley speed—fpm (5 step) variable	0–30

Brakes are provided for hook, trolley, and crane travel. They include both the electric and hydraulic shoe type, with shunt coil and manual release lever.

The bridge crane is controlled from a pushbutton station in an operator's cage mounted below and at one corner of the crane. Access to the crane is at two locations from the plant catwalks. One means of access is from the operator's cab to a plant catwalk on the pumping plant wall; the other is by ladder from the operator's cab to the bridge walkway. Access is also provided from the bridge walkway to a catwalk mounted on the end wall of the Pumping Plant.

The 10-ton gantry crane is an outdoor traveling type and operates on steel rails in the plant gate deck. The lifting mechanism consists of a lifting beam suspended from twin snatch blocks.

The rated capacity and speeds of the gantry crane are as follows:

Rated capacity, tons	10
Number of trolleys	1
Span, feet—inches	10′—6″
Hoist speed with maximum working load, fpm (two speeds)	4.5 and 9.0
Gantry travel speed with maximum working load, fpm	35
Trolley travel speed with maximum working load, fpm	4
Maximum lift, feet—inches	46′—0″

Auxiliary Service Systems

The auxiliary service systems at the plant are described in Chapter I of this volume. Items unique to this plant are discussed below.

Motor Cooling Water System. Water for the cooling water system is supplied by 11 pumps (four of which are standby) located in the cooling water gallery (Figure 241). Cooling water is supplied to the motor air coolers, motor-bearing heat exchangers, and pump-bearing heat exchangers. Each cooling water pumping unit consists of a split-case, double-suction, single-stage, vertical, centrifugal pump directly connected to an electric motor, check valve, automatic self-cleaning strainer, and associated valves and piping. The pumps are arranged so that there is one standby for each of the two units except for Unit No. 3, which has one regular and one standby pump.

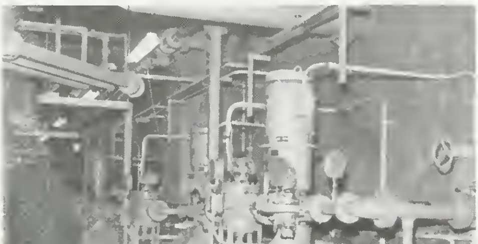

Figure 241. Cooling Water Pump Gallery

Electrical Features

General

The electrical installation includes a 230-kV switchyard, power transformers, motors, switchgear, and auxiliary systems for station service, communication, and protection of equipment and personnel.

Discussion of auxiliary systems or equipment which are common to other plants in the Project is included in Chapter I of this volume.

Description of Equipment and Systems

The 230-kV switchyard contains two circuit breakers with their isolating switches and one bypass disconnect switch (Figure 242). Two transmission lines and one load line connect to the switchyard. Revenue metering was installed in the switchyard. The load line drops to a bus rack at the Pumping Plant where the power transformers are connected through disconnect switches and reduce the voltage to 13.2 kV (Figure 243).

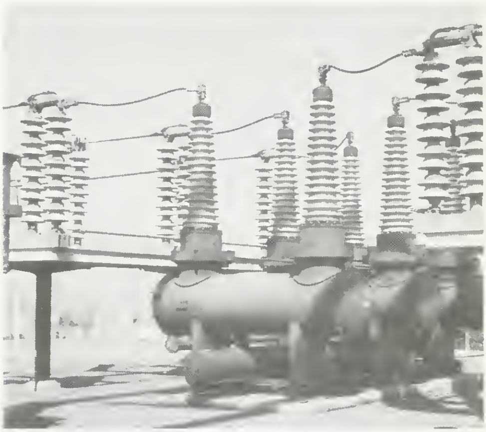

Figure 242. 230-kV SF_6 Circuit Breaker

Figure 243. Transformer Bus Yard

Seven motors are presently installed, with four additional units to be added in the future (Figure 244). The motors are operated and protected by metal-clad circuit breakers and relays. Capacitors and lightning arresters on the line side of each motor protect from transient overvoltages. A nonsegregated-phase bus connects the low-voltage side of the power transformers to the switchgear, and the same type of bus also connects the motors to the switchgear. The larger motors are started with a reactor in the neutral to effectively reduce voltage and with water depressed from the pump case. A full-voltage dewatered start without a reactor is used for the smaller motors.

A double-ended substation is used to distribute station service energy at 480 volts to various distribution centers located throughout the plant (Figure 245). Two transformers are included in the substation, connected on the low side with secondary breakers and bus, and 480-volt breakers protect and switch the distribution circuits.

Protective relays, annunciators, metering instruments, and control devices are mounted on the switchgear and auxiliary sections. The boards are arranged on a unit basis (Figure 246).

A control room is provided for normal operation of the plant although it can also be operated locally at the units. Certain operation and monitoring functions also may be performed remotely from the plant in the area control center. The plant controls use a computer as the central base of the system. The system will control, monitor, log data, display, and annunciate all necessary points of the plant and switchyard (Figures 247 and 248). Volume V of this bulletin describes the control systems in the plant and area control center.

Figure 245. 480-Volt Station Service Substation

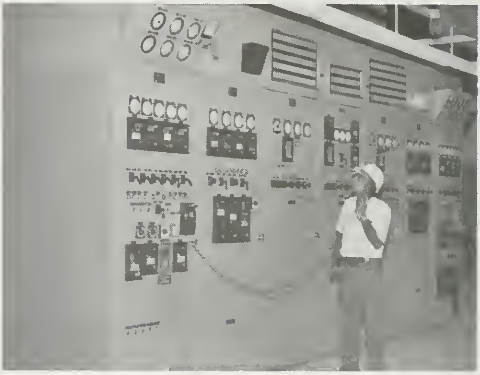

Figure 246. 15-kV Switchgear for Two Units

Figure 244. 11,250-Horsepower Synchronous Motors

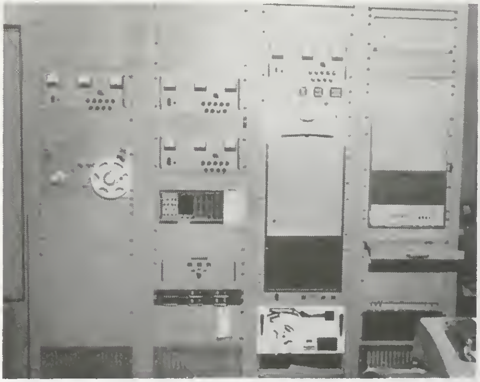

Figure 247. Control System Computer Equipment

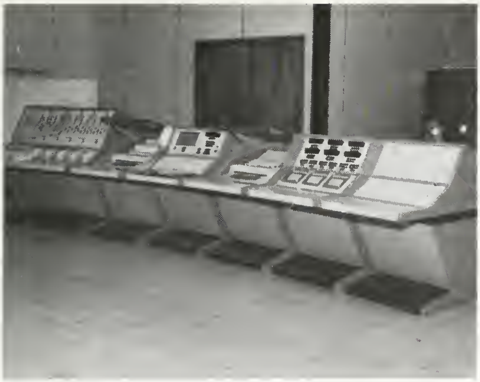

Figure 248. Control System Operotor's Console

Equipment Ratings

Motors

Manufacturer: General Electric Company
Type: Vertical-shaft, synchronous
Power factor: 95%
Volts: 13,200

Motors Nos. 1 and 2

Horsepower: 11,250
Speed: 400 rpm

Motors Nos. 3 through 7

Horsepower: 34,500
Speed: 225 rpm

Power Transformers

Manufacturer: General Electric Company
Volts: 220-13.2 kV, grounded-wye
Taps: In the high-voltage winding, 2½ and 5% above and below rated voltage
Phase: 3
Type: OA/FA
Connection: Wye-Delta

Transformer No. 1

kVA: 36,000/48,000

Transformers Nos. 2 and 3

kVA: 43,125/57,500

Station Service

Number of transformers: 2
Volts: 13,200—480Y/277
Phase: 3
kVA: 1,000/1,333
Type: AA/FA

Motor Starting Method

Three methods of motor starting were studied: full-voltage, full-voltage with a reactor in the neutral, and reduced-voltage with a tap in the power transformers. In addition to these starting choices, watered or dewatered starting was evaluated.

Starting with the pump casing watered is the most dependable arrangement since a minimum of auxiliary equipment is required; however, motor starting and synchronizing torques are much higher than with dewatered starts. Estimates of motor costs favored the dewatered starts by approximately 30%. Starting with the pump casing dewatered was selected for both the smaller and larger size units.

Of the three methods of motor starting, full-voltage is normally the first choice due to minimal auxiliary equipment required, even though high starting currents and maximum winding stresses exist in motors started in this manner. The larger motors at Delta Pumping Plant have a rating higher than other motors in the service area of the utility company. After examining their system capabilities, the utility set limits which precluded full-voltage starting of the large motors. Although reduction of starting inrush would involve higher costs, stresses in the motor windings would be reduced. Since the motors are started daily for off-peak pumping, reduction of stresses has significant advantge in reducing maintenance costs. Full-voltage starting kVA for the smaller motors did not exceed the limit of the utility company and was selected as the starting method. It was also concluded that the windings of the smaller units could be adequately tied and braced for this service.

The second method studied for the larger motors, that is, starting full-voltage with a reactor in the neutral, was selected. This method met the utility inrush limits and also reduced starting currents. Although full voltage is applied to the motor terminals, the voltage drop across the windings is reduced by inserting a single-phase reactor in each phase winding of the wye-connected motor at the neutral end, ahead of the ground connection. After the motor is synchronized, reactors are shorted together, leaving the three paralleled reactors in the motor neutral grounding circuit. A standard, 15-kV, metal-clad, circuit breaker was installed to short the reactors.

Reduced-voltage starting by means of taps in the low-voltage winding of the power transformers was the third method studied but was not selected. There was no pronounced difference in costs or advantages of this system over the selected method using reactors. The choice was made essentially because of the extra bus and breakers needed for the reduced voltage and space limitations.

230-kV Interconnections

Two transmission lines connect to the switchyard and one load line connects to the power transformers at the plant (Figure 249). A circuit breaker was installed in each of the transmission lines. Two independent sources of power were required for dependability of service, with either line capable of carrying the full load. This was accomplished by opening an existing tie line between two utility sources and looping the line in and out of the switchyard, thus providing two sources of power. A bypass switch was installed on the line side of the two break-

Figure 249. 230-kV Switchyard

ers. This will enable one breaker to be removed from operation for maintenance and still retain a circuit through the switchyard for the utility company.

Other switchyard arrangements were considered including the main-and-transfer bus and ring bus. With only three lines required for the chosen method, increased cost of the equipment and structures for alternate bus arrangements eliminated the other configurations.

Construction

Contract Administration

The major portion of the work required to construct the Delta Pumping Plant was included in two large contracts: Specification No. 64-09, Delta Pumping Plant and Discharge Lines, and Specification No. 66-02, Completion of Delta Pumping Plant. In addition, several contracts were awarded to furnish and install the electrical and mechanical equipment. Table 4 shows general information for the major contracts.

Bowl and Intake Channel Excavation

The initial excavation for Delta Pumping Plant was performed concurrently with the intake channel excavation.

Twin-engine, 40-cubic-yard-capacity, earth movers excavated material from the lower elevations and hauled the material up the steep grades to the spoil areas. Three of these units had tandem scrapers to excavate the softer and more accessible material. The same capacity single-engine earth movers excavated and hauled material from the higher elevations. Tractors and twin-engine rubber-tired dozers were used as pushers to facilitate loading the earth movers. Tractors with rippers prepared the material for loading. Blasting also was necessary in sandstone concretions.

Dewatering Operations

The intake channel contractor excavated a 2½-mile-long ditch from the construction site to Italian Slough to carry water encountered in the intake channel to a sump for disposal into the Slough. Subsurface water was initially intercepted with 94 horizontal drains, ditches, and sumps. The water was then pumped from the sumps into the ditch to Italian Slough.

Structural Excavation and Backfill

Pumping Plant Substructure. The pumping plant bowl was further excavated to elevation −36 feet under the centerline of the pump units (Figure 250). The excavated material was used to construct an access ramp about 100 yards upstream of the plant. After its completion, the service bay was excavated to grade including excavation of the service bay sump to elevation −41 feet. Minor blasting was required during excavation to remove boulder tops protruding above finished grade. The contractor used dozers with rippers, a roadgrader scarifier, and air hammers to loosen the material. A loader and dump trucks were used to haul the material away.

TABLE 4. **Major Contracts—Delta Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Delta Pumping Plant and discharge lines	64-09	$6,332,053	$6,790,499	$402,525	8/25/64	8/31/66	Guy F. Atkinson Co.
Pumps (7)	64-10	1,621,365	1,865,551	162,479	7/ 3/64	5/28/69	Newport News Shipbuilding & Dry Dock Co.
100-ton bridge crane	64-20	90,000	90,000	--	8/11/64	2/ 8/66	American Crane & Hoist Co.
Discharge valves	64-48	1,070,000	1,148,572	--	5/24/65	4/18/69	Westinghouse Electric Corp.
Motors	65-12	3,045,394	3,123,356	35,409	5/17/65	4/30/69	General Electric Co.
Power transformers	65-32	493,008	511,815	--	8/11/65	8/15/68	General Electric Co.
230-kV power circuit breakers	65-35	148,970	157,246	600	8/25/65	3/28/68	Westinghouse Electric Corp.
13.8kV switchgear and station service	65-40	508,682	489,138	--	9/13/65	5/ 2/69	General Electric Co.
Completion of Delta Pumping Plant	66-02	2,867,118	4,023,433	370,288	2/ 7/66	2/14/69	Baldwin Warren Co.

Discharge Lines and Manifolds. Excavation for the discharge lines was started at the top of the lift, and material was bulldozed down the slope into stockpiles. There, it was loaded onto dump trucks with a loader and hauled to the backfill stockpile. The anchor block foundations were excavated during the same operation.

Large equipment had limited application in the excavation for the discharge manifolds; consequently, extensive use of hand labor was required to obtain the final configuration.

Outlet Structure. Final excavation for the outlet structure was performed by a large dozer with ripper followed by a grader with scarifier. Areas with restricted access were fine graded with hand tools. All excavated material was hauled to the backfill stockpile.

Backfill. The four types of backfill used during first-stage construction of the Delta Pumping Plant were consolidated backfill, compacted backfill, gravel blanket material, and common backfill.

Consolidated backfill was free-draining cohesionless material used to fill any overexcavation for the discharge lines and to provide a bedding for the steel pipe. The material was consolidated to 80% relative compaction. Starting at the bottom of each discharge line, the backfill material was flooded and vibrated under the lines from the invert to a point on the circumference about 60 degrees from the bottom. The saturating and vibrating were performed simultaneously, with consolidation achieved concurrently on both sides of the discharge line.

Compacted backfill material was used around structures and between the discharge lines (Figure 251). The material was moistened to within 2% of optimum moisture content, and 6-inch-thick layers were alternately spread and compacted to 95% relative compaction with vibratory rollers.

A 2-foot-thick gravel blanket of free-draining material was placed around the pumping plant walls, behind the counterfort walls, around the sleeve coupling chambers and manifold encasements, and underneath the gravity intake walls. The blanket, placed concurrently with the compacted backfill, ranged in size from $\frac{3}{16}$ to $1\frac{1}{2}$ inches and was compacted to 70% relative compaction by an oscillating turtle-back tamper.

Common backfill material was obtained from the excavations and processed to remove all large rocks. It was placed in uncompacted layers to a depth of 3 feet above the discharge lines.

Pneumatically Applied Mortar

The material composing the plant foundation was hard, brittle, and susceptible to excessive air slaking. To protect the foundation and to even the final grade, a 1-inch-thick layer of gunite was applied after all loose material had been removed with high-velocity air jets (Figure 252). The gunite prevented damage

Figure 250. Excavation of Plant Foundation

Figure 251. Placement of Compacted Backfill Between Discharge Lines

Figure 252. Compacted Plant Foundation Excavation with Pneumatically Applied Mortar Cover

from heavy rains, reduced air slaking, and expedited form cleanup and grade acceptance on all bottom lifts.

Concrete Placement

The major portion of the concrete required for construction of the plant was furnished under Specification No. 64-09. The concrete batch plant consisted of a batcher with unitized cement and pozzolan bins, hoppers for three sizes of aggregate, a mixing plant with two 2-cubic-yard mixers, and an ice storage and crusher building. The mixing plant was elevated to allow a truck with two 4-cubic-yard buckets to drive under the hopper. The concrete was trucked to the placement site where the buckets were unloaded by the gantry crane or the truck crane. Consolidation was accomplished with 6-inch pneumatic vibrators where possible; smaller vibrators were used in the thin walls and slabs.

Concrete for the completion contract, Specification No. 66-02, was furnished in dry batches from a source 25 miles from the plant and was mixed at the site in a mobile mixer. The concrete was placed in a conventional manner (Figure 253). Just prior to concrete placement, a large slide demolished the forms and the reinforcement steel; so the first lift was the central block for Unit No. 10 in Bay No. 5.

The contractor's methods and procedures for scheduling and controlling production were excellent. Because of this, plant concrete placement took place without major difficulties.

Discharge Lines

The irregular, steel, discharge line sections (tapers, wyes, and elbows) were unloaded from low-bed trailers near the job site where cleaning, coating, and wrapping were accomplished by hand. The straight sections were unloaded onto a timber skidway along which they were rolled onto a set of rubber-tired trunnions where they were rotated slowly and machine sandblasted, primed, and wrapped.

Each of the coated wye, manifold, and elbow sections was reloaded onto a low-bed trailer towed by a large crawler tractor from the coating area, down the slope to the positioning crane, where it was unloaded and set in position to approximate alignment on sandbag supports. The positioning crane worked from a timber mat. The mat and crane had to be precisely positioned for each section of pipe for the manifolds and wyes because of the limited reach and swing of the crane.

As soon as possible, the contractor changed his method of transporting and positioning pipe sections to eliminate the need for precise crane location. Timber rails were installed from the top of the discharge line down to the last section of pipe in place in each line; then the pipe sections were set on a heavy sled which rode on greased rails. The sled was then lowered down the slope into position. Immediately after positioning, all sections were jacked into correct alignment and set to proper grade; then the joints were

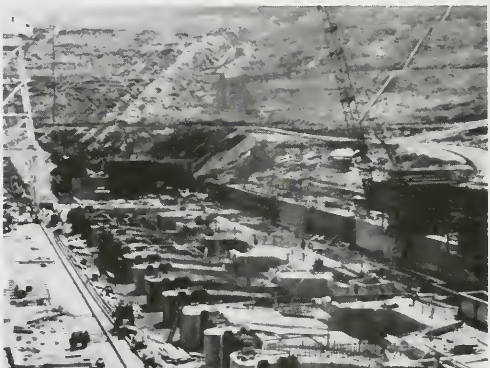

Figure 253. Concrete Work

trimmed, dogged, tacked to correct joint fit-up, and then welded (Figure 254).

Initially, the two closure joints on each discharge line were to be closed with a butt strap welded to the interior of the pipe after the pipe had been covered with backfill. Field tests revealed that interior welding burned and ruptured the exterior coating. To solve this problem, a metal collar was constructed around the exterior of each pipe which was filled with concrete grout after the compacted backfill and joint closure was completed.

The cleaning and coating of the interior of the discharge lines were accomplished in-place. The manifold sections were done by hand, and the discharge lines were done by a machine mounted on a jumbo pulled through the lines at controlled rates.

All interior coating was inspected with an Elcometer for thickness and a low-voltage detector for holidays. All manifolds required buildup to obtain the required thickness. After the manifolds and lines were completed, they were hydrostatically tested (Figure 254).

Outlet Structure

The outlet transition structure concrete was placed with 2-cubic-yard buckets spotted with a 45-ton truck crane. All placements were made without particular difficulty.

The last section of each discharge line was installed after completion of the outlet structure and tied together with a concrete collar. This connection was a 2-foot-long by 1-foot-thick reinforced-concrete collar around the circumference of the pipe, tied to it and the stiffener rings by reinforcing steel. It was separated from the concrete of the outlet structure by a 1-inch thickness of elastic joint filler. Grout was used for the collars and, after the discharge liner had been backfilled for over 30 days, the joints were sealed with joint sealant.

Figure 254. Wooden Skids and Carriage Used to Lower Pipe Sections Into Place

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 255 through 288).

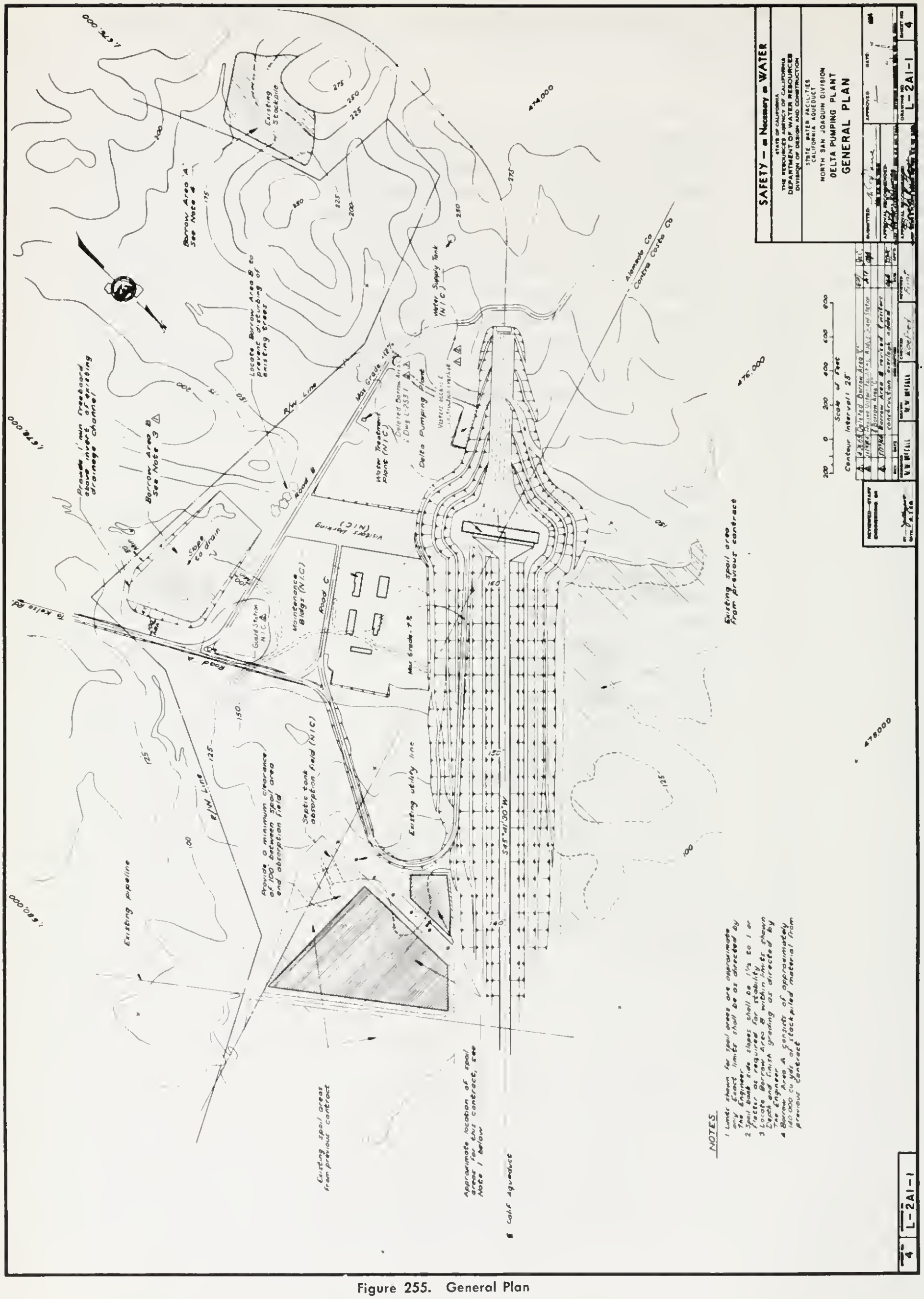

Figure 255. General Plan

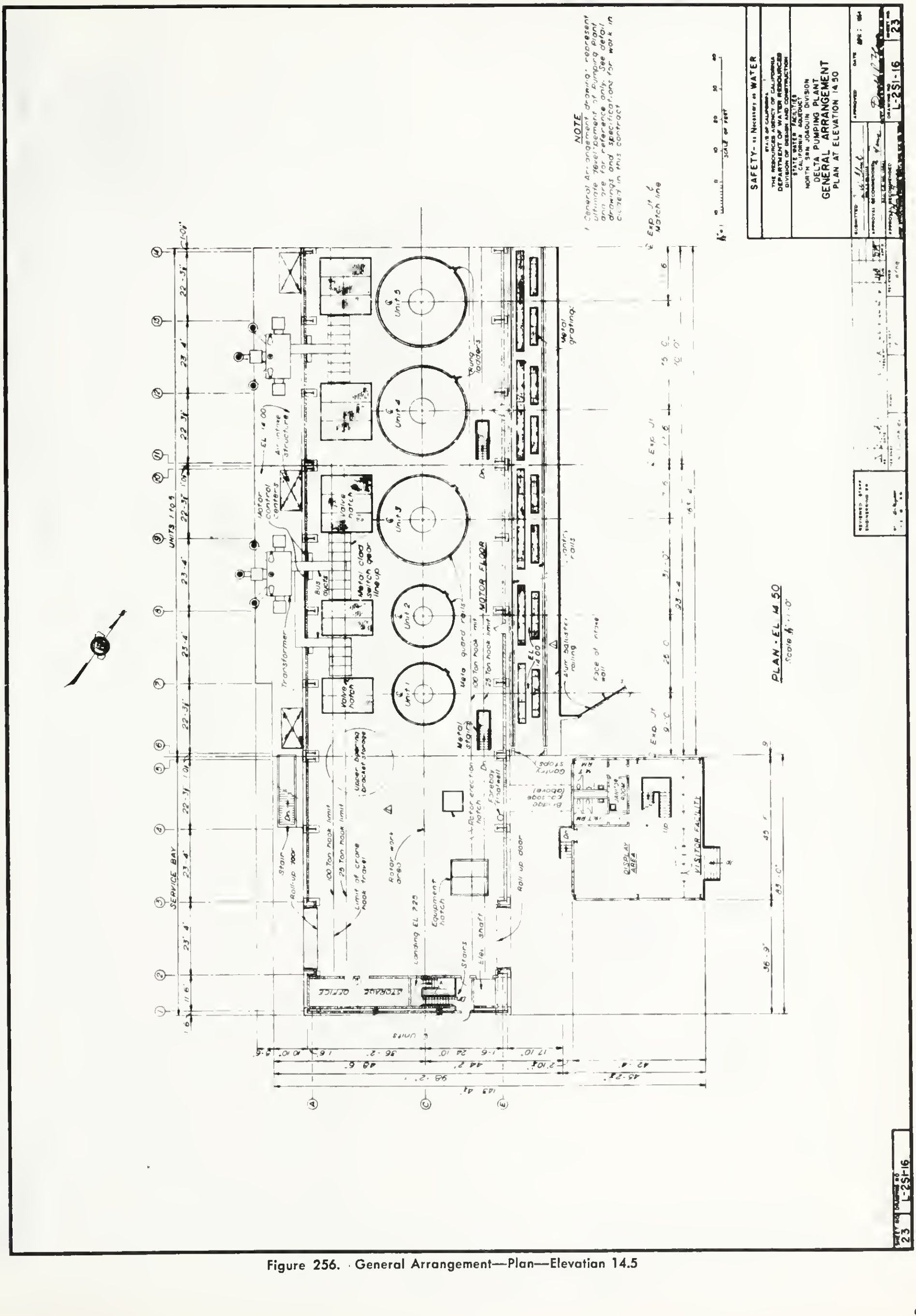

Figure 256. General Arrangement—Plan—Elevation 14.5

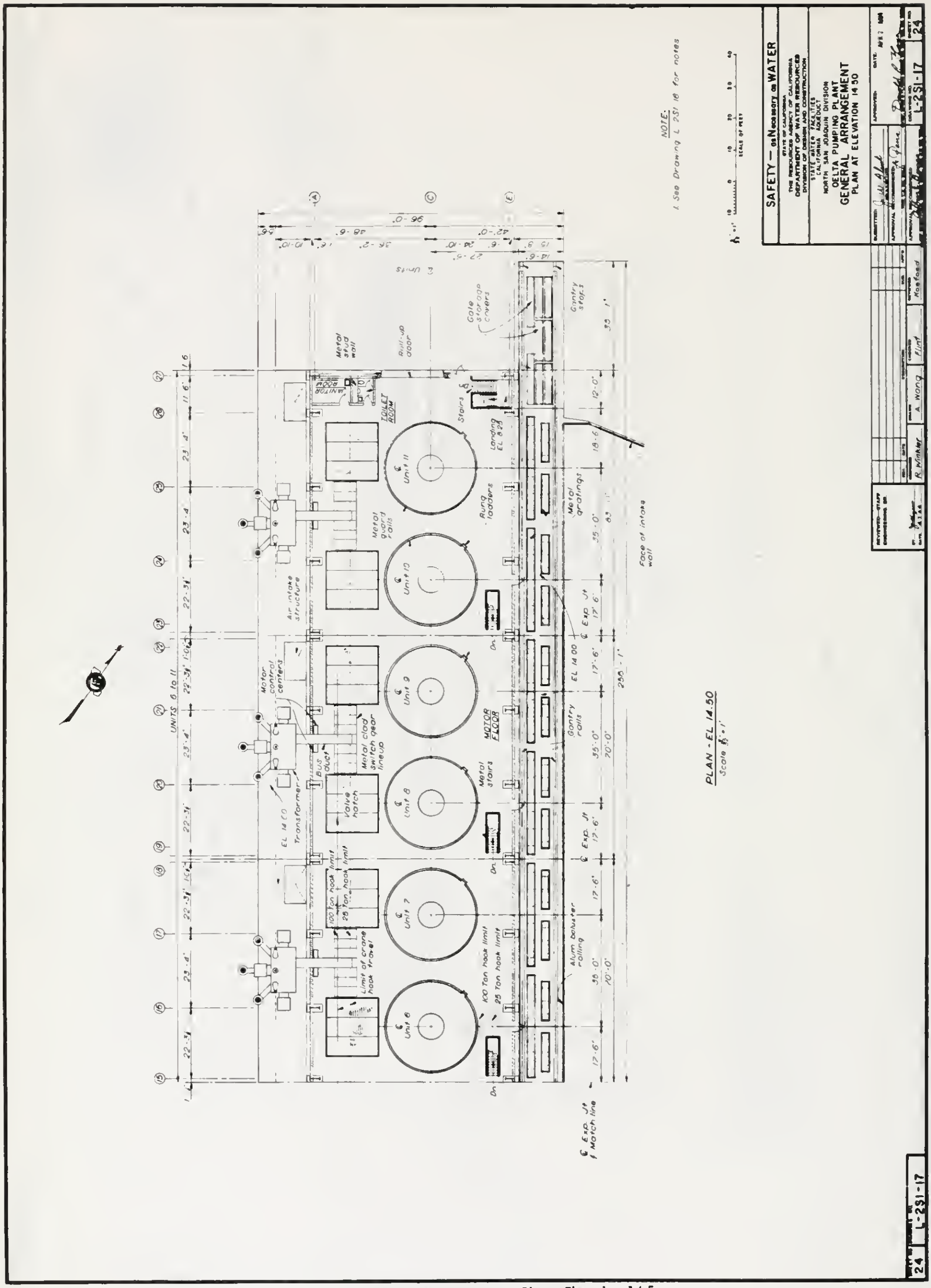

Figure 257. General Arrangement—Plan—Elevation 14.5

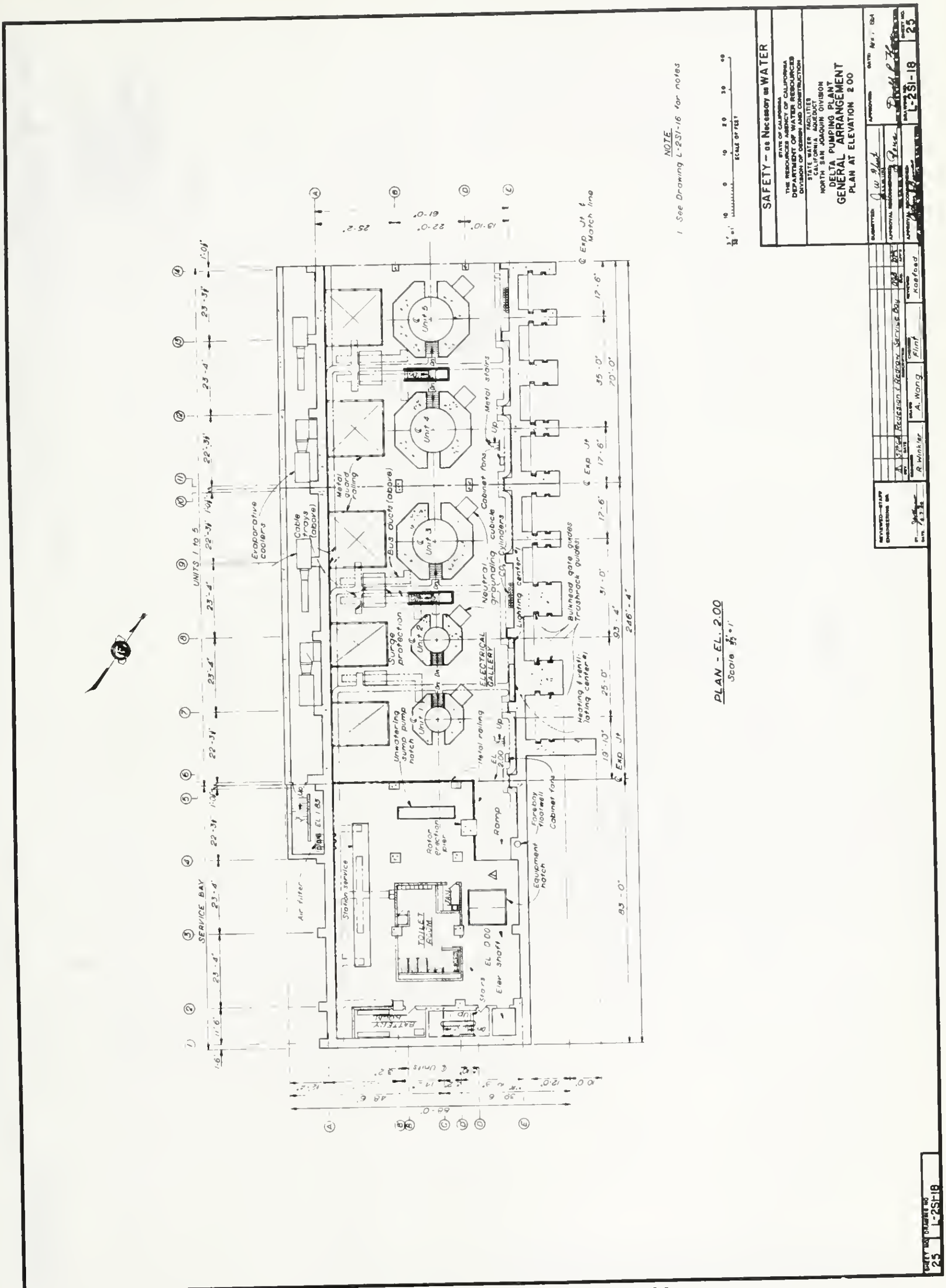

Figure 258. General Arrangement—Plan—Elevation 2.0

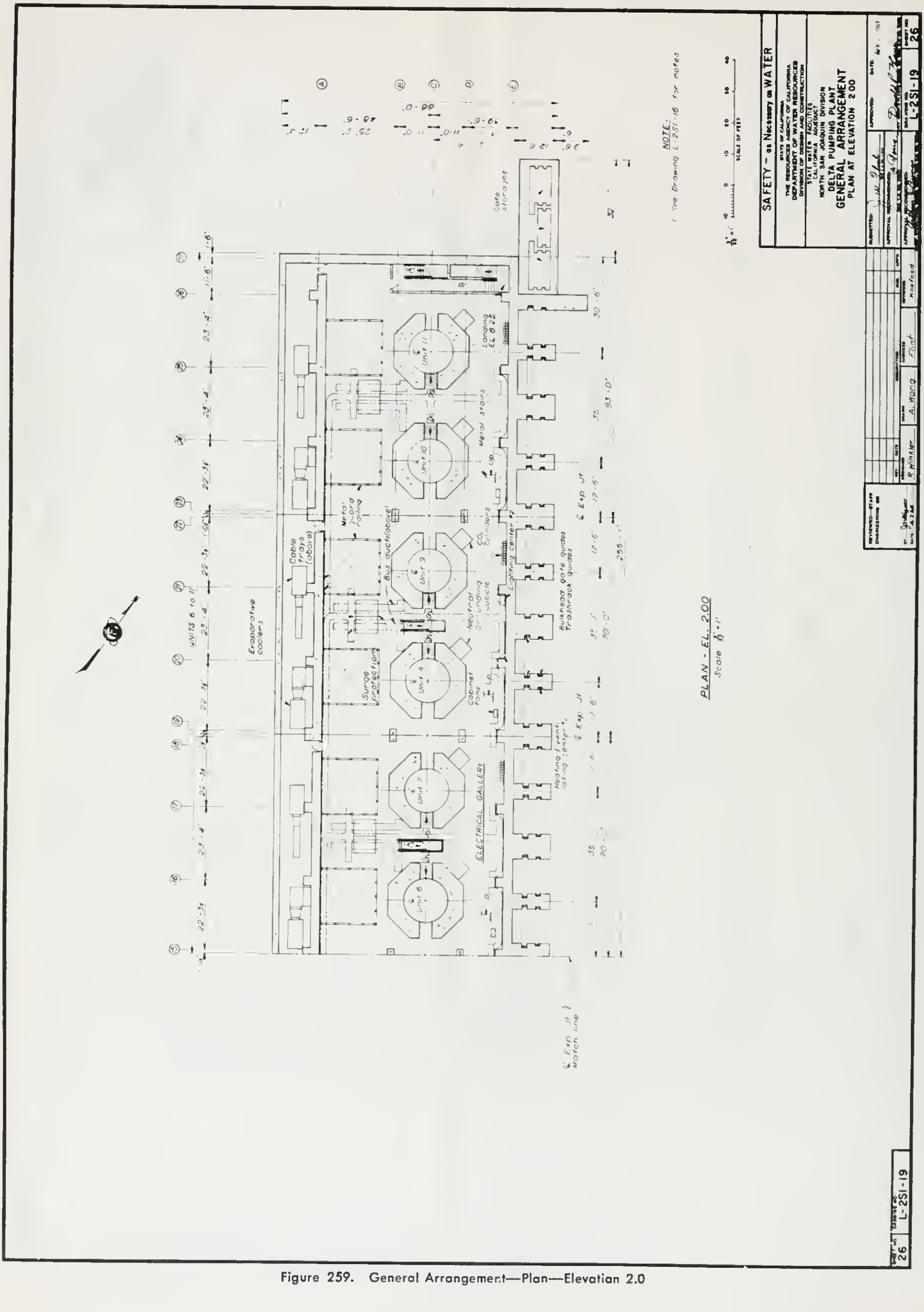

Figure 259. General Arrangement—Plan—Elevation 2.0

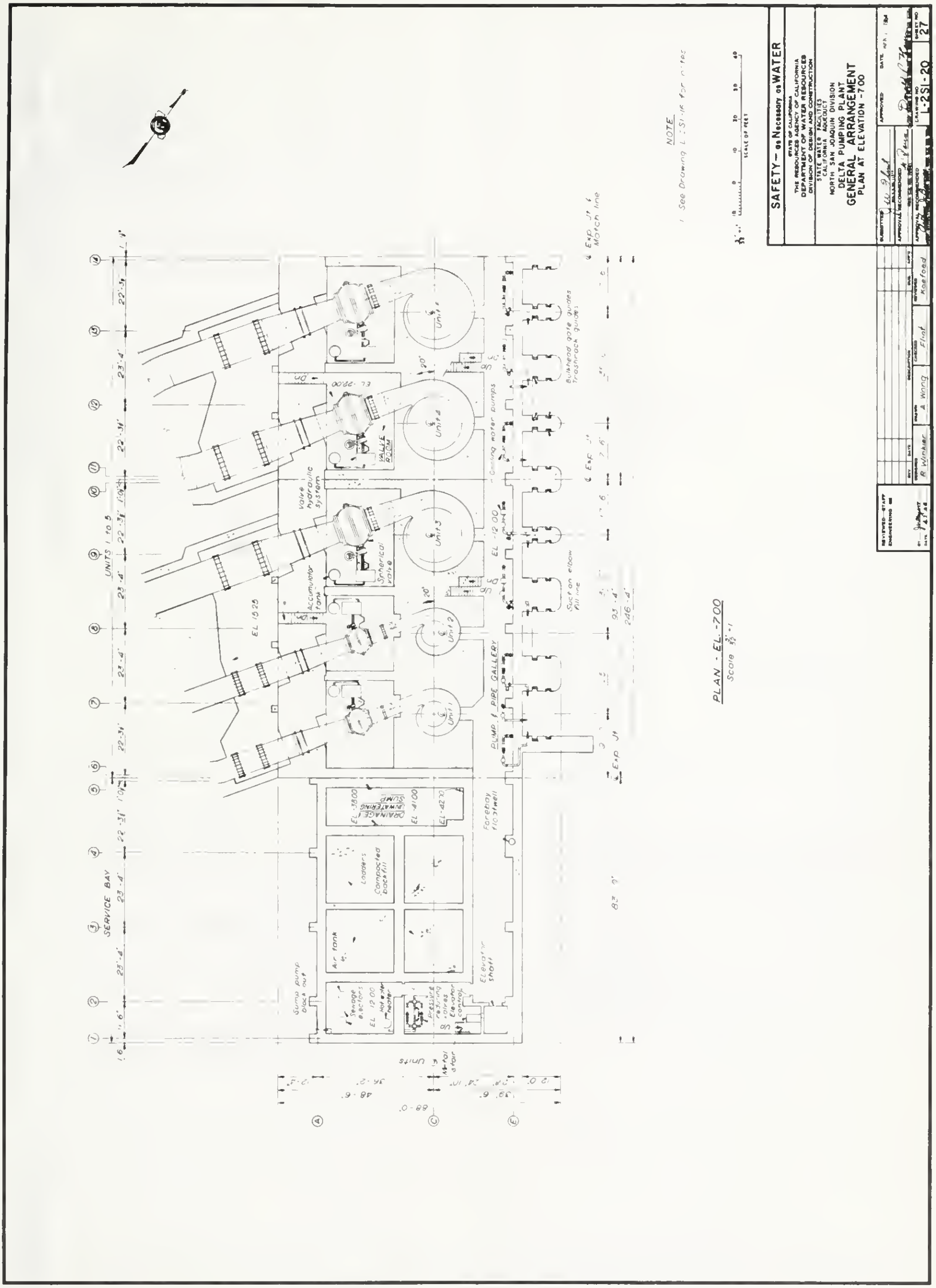

Figure 260. General Arrangement—Plan—Elevation −7.0

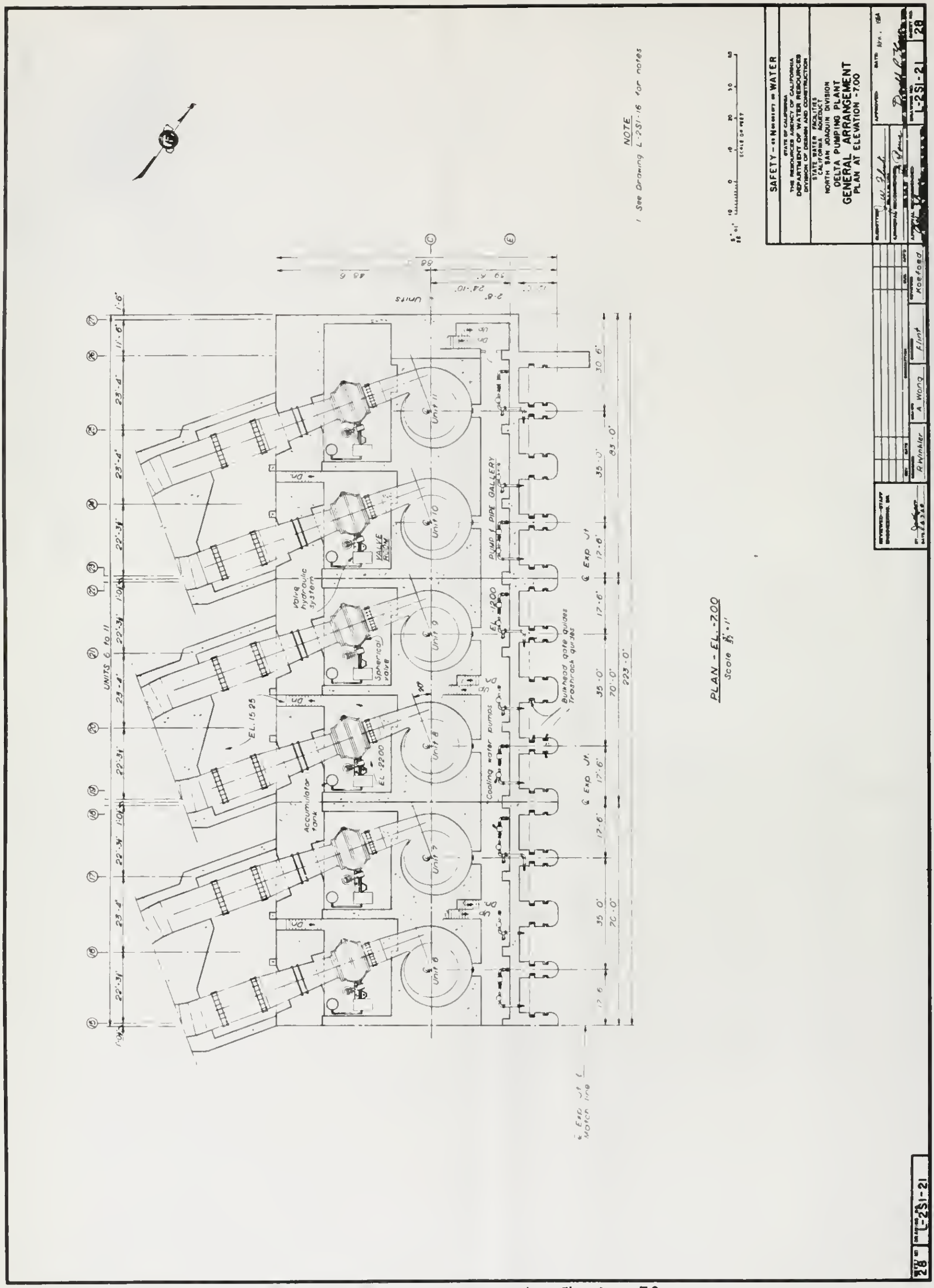

Figure 261. General Arrangement—Plan—Elevation —7.0

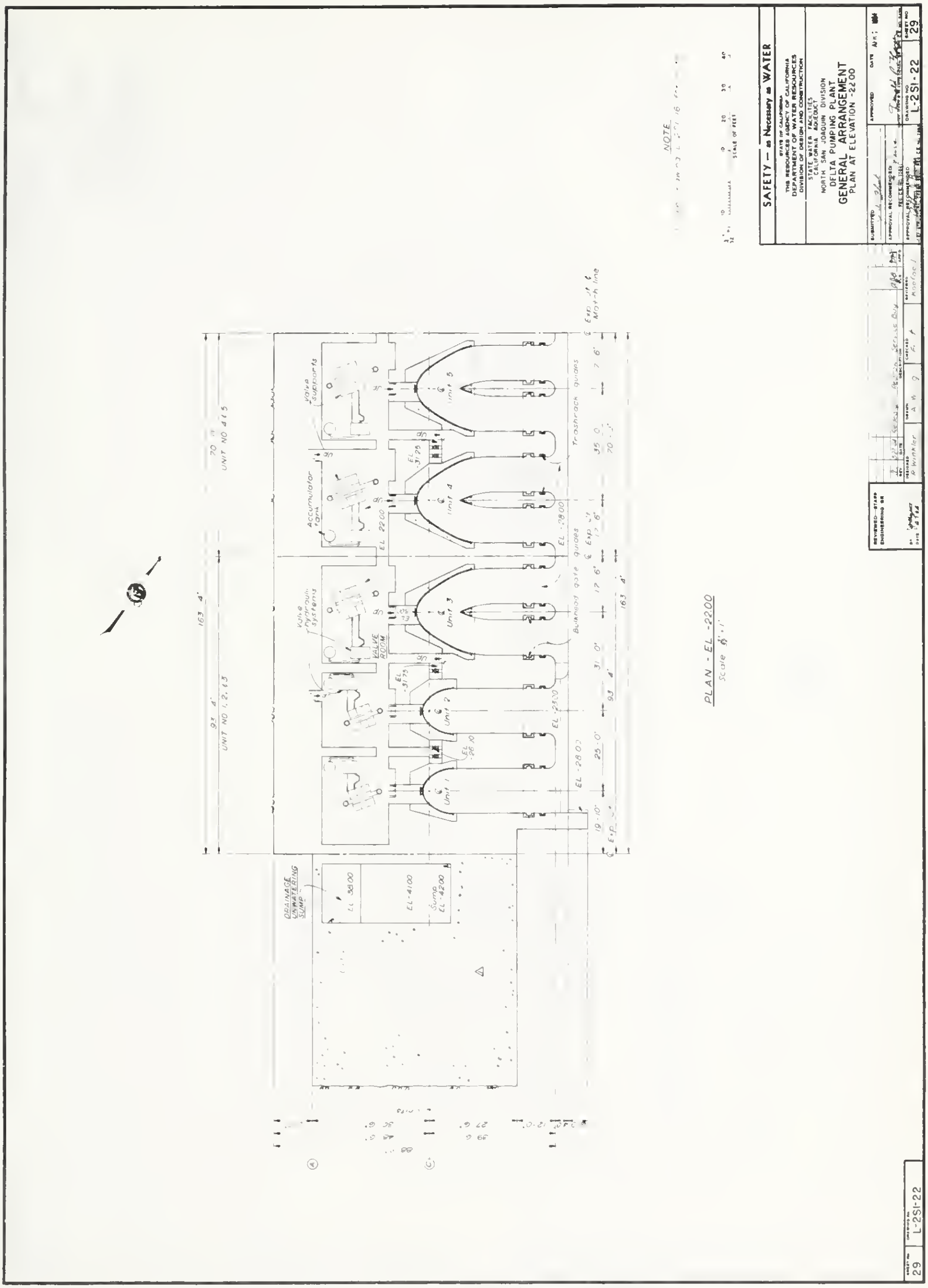

Figure 262. General Arrangement—Plan—Elevation —22.0

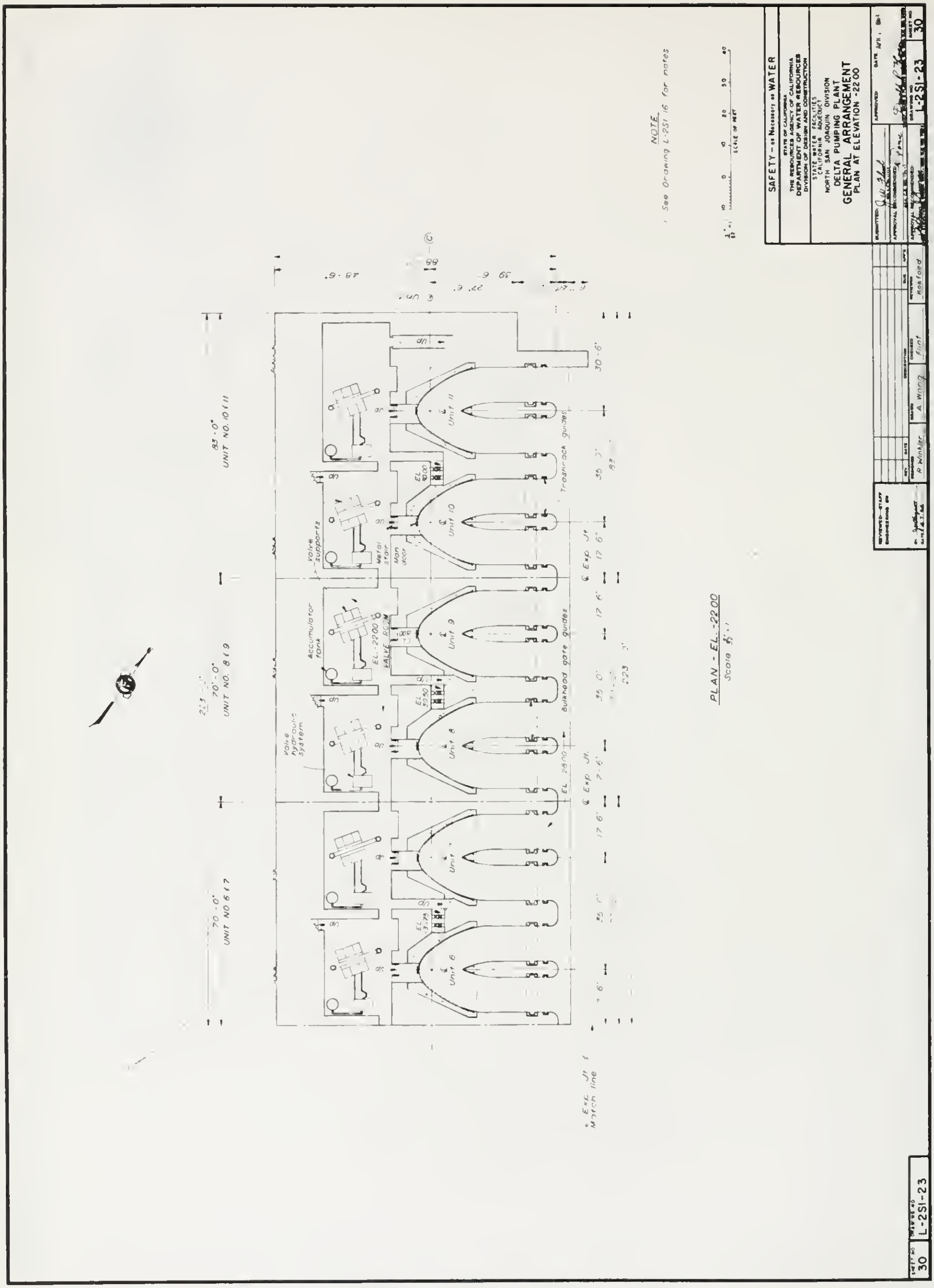

Figure 263. General Arrangement—Plan—Elevation —22.0

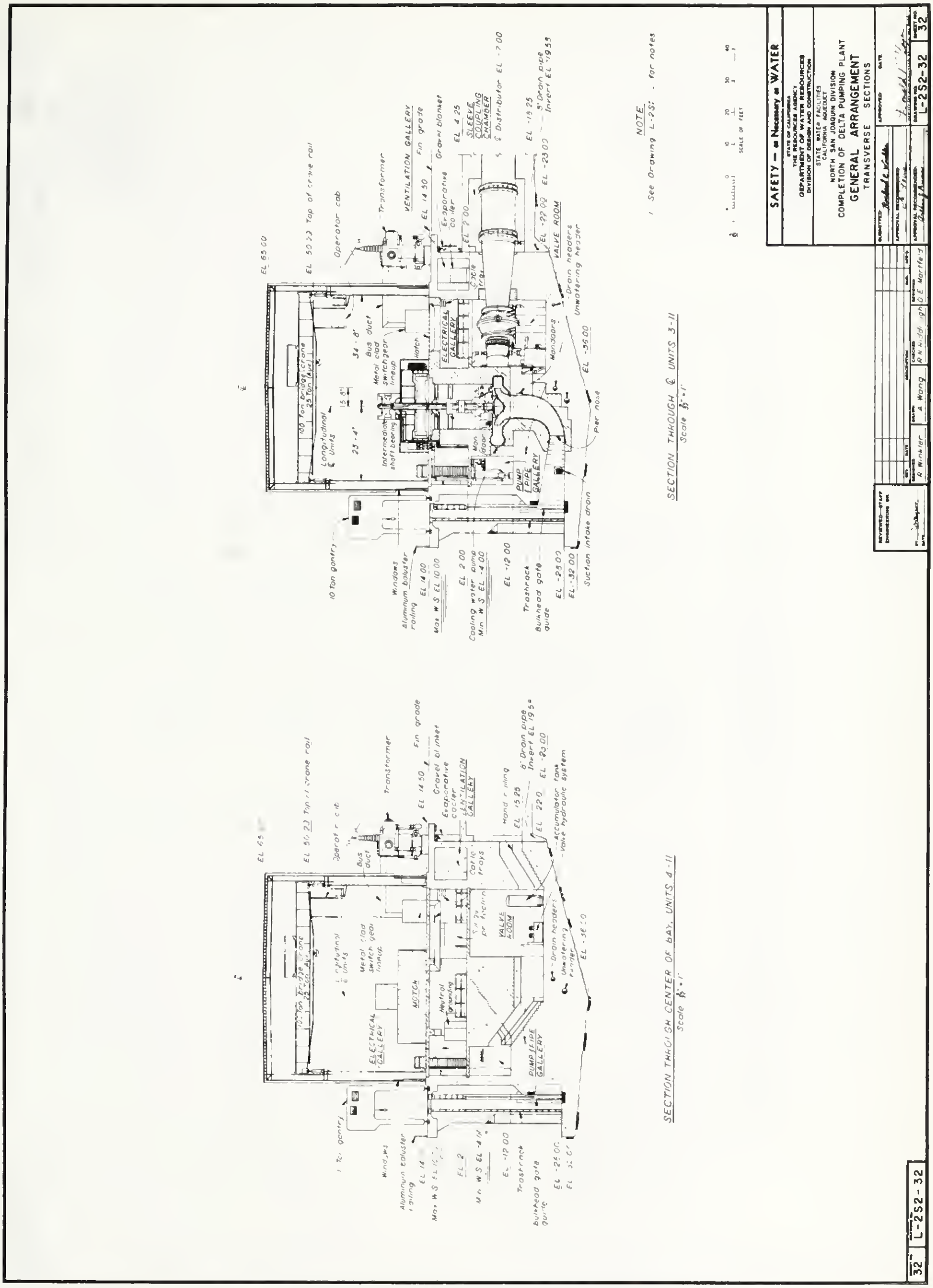

Figure 264. General Arrangement—Transverse Sections.

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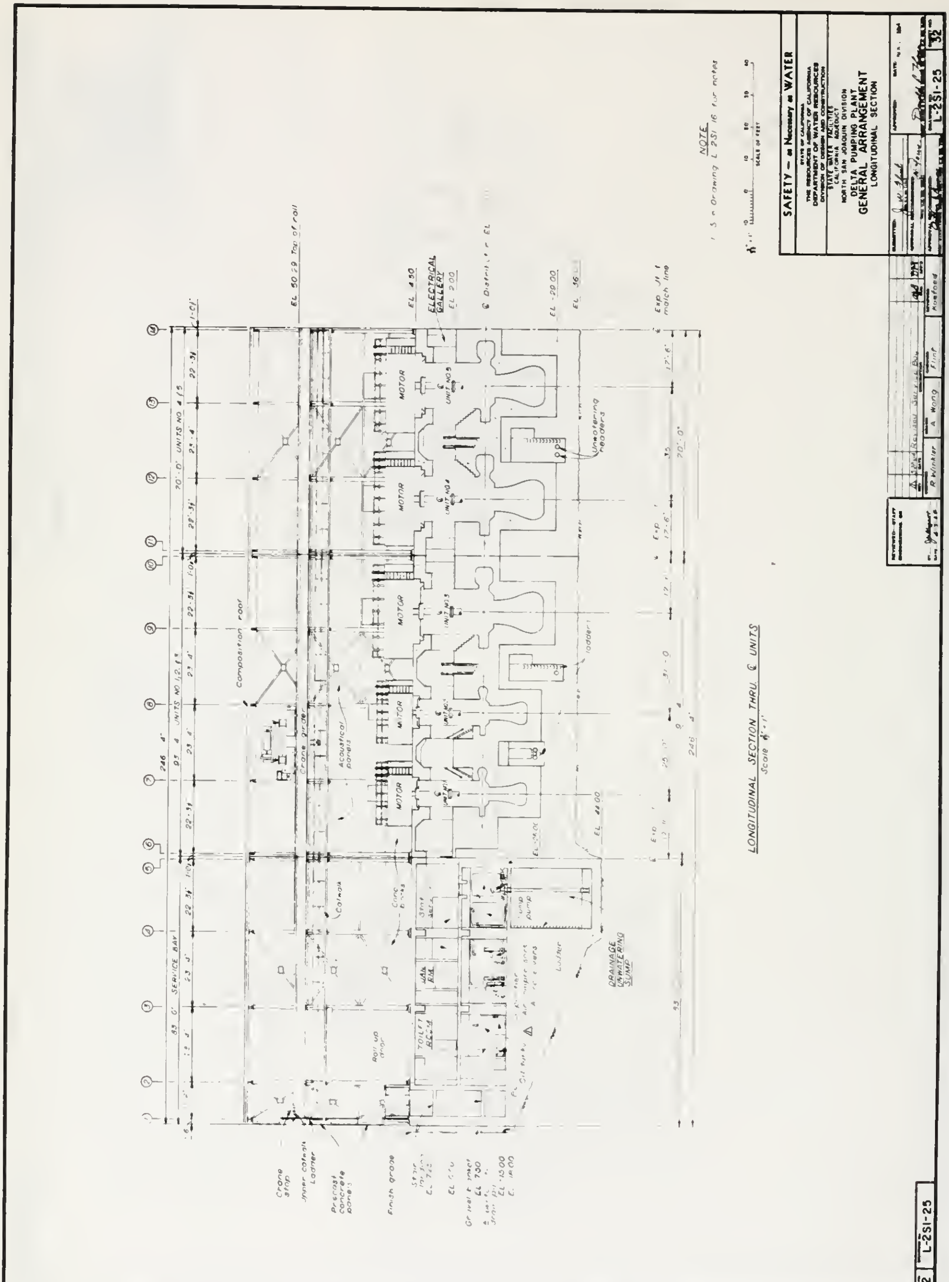

Figure 265. General Arrangement—Longitudinal Section

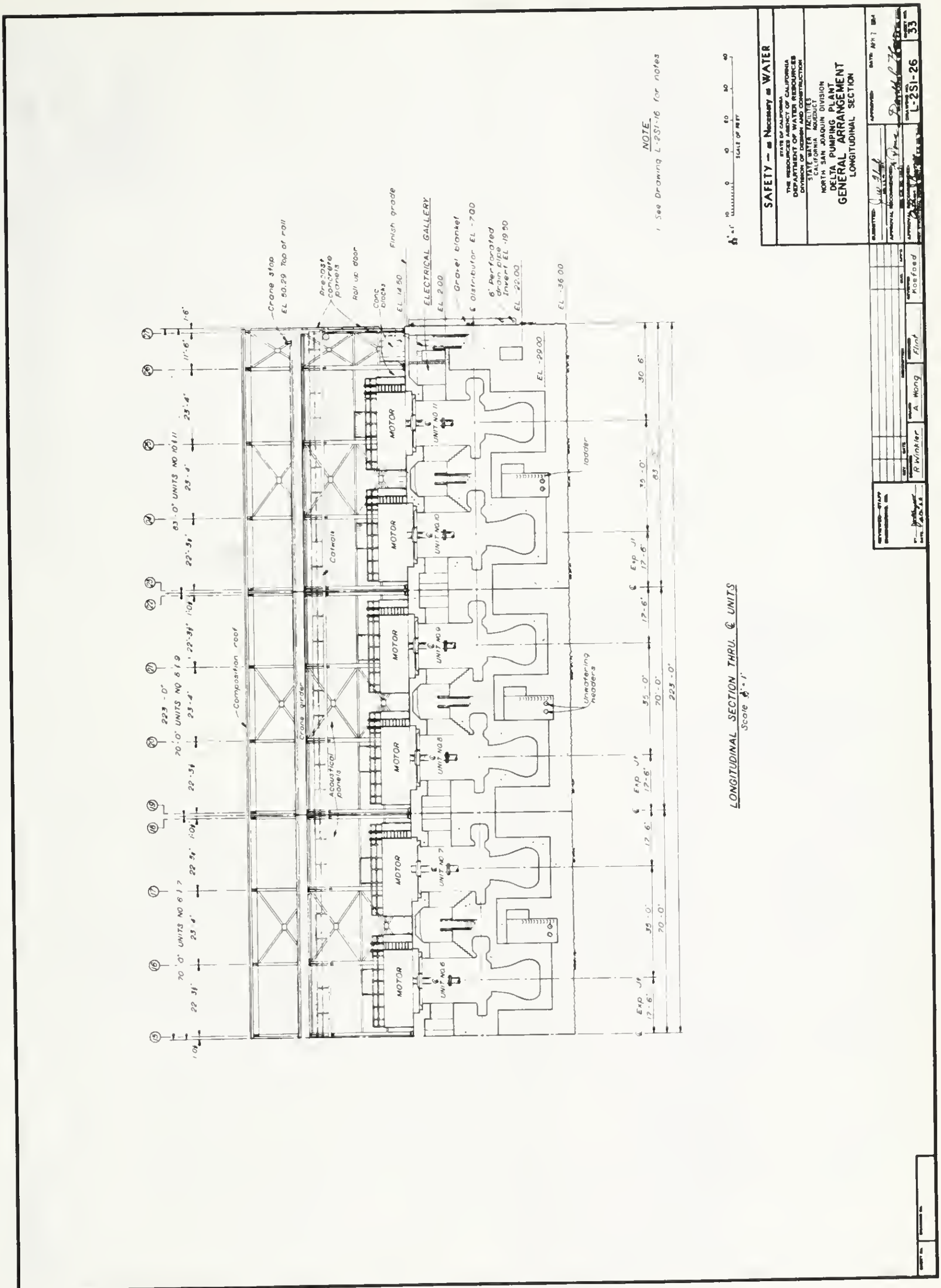

Figure 266. General Arrangement—Longitudinal Section

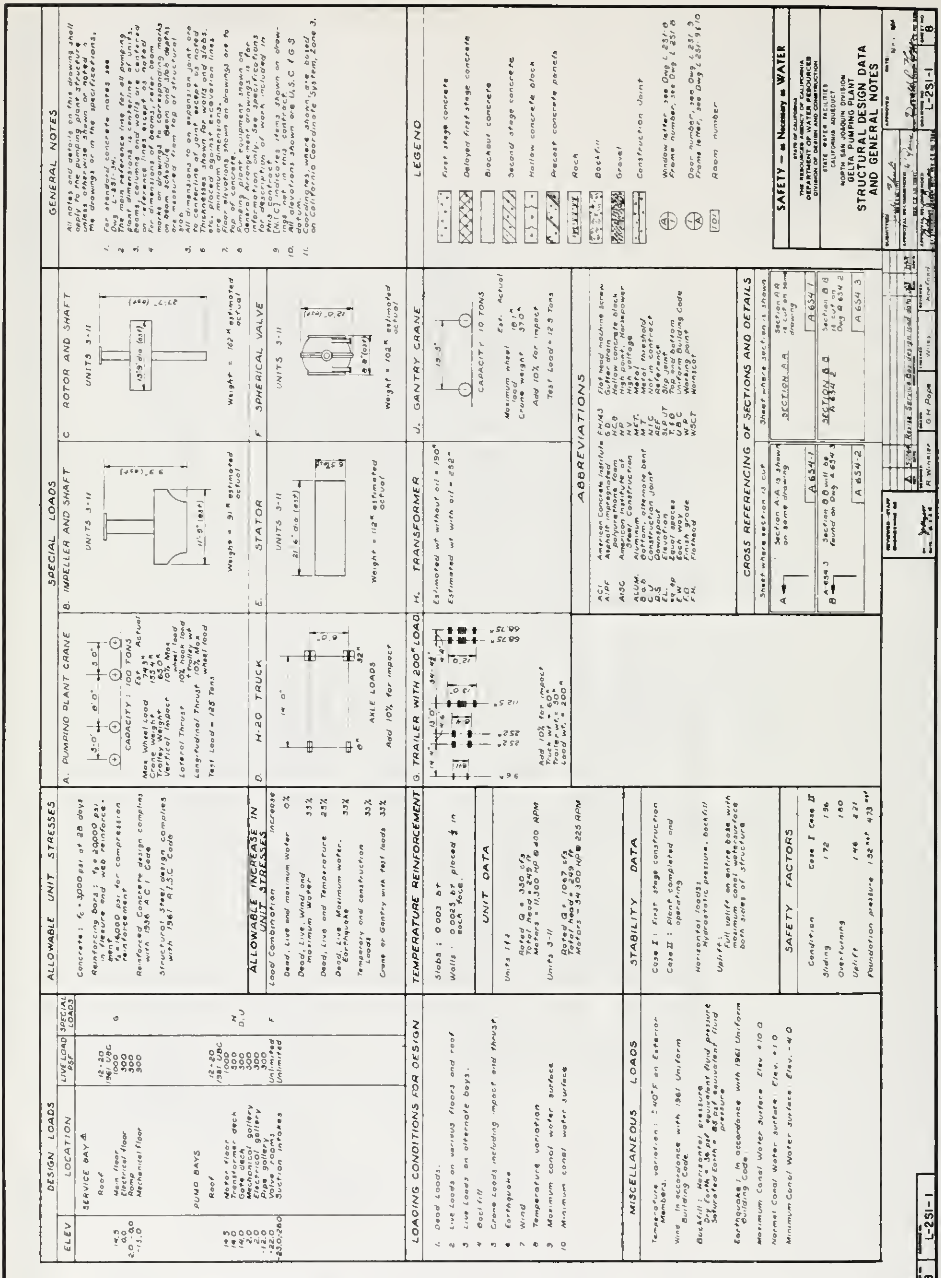

Figure 267. Structural Design Data

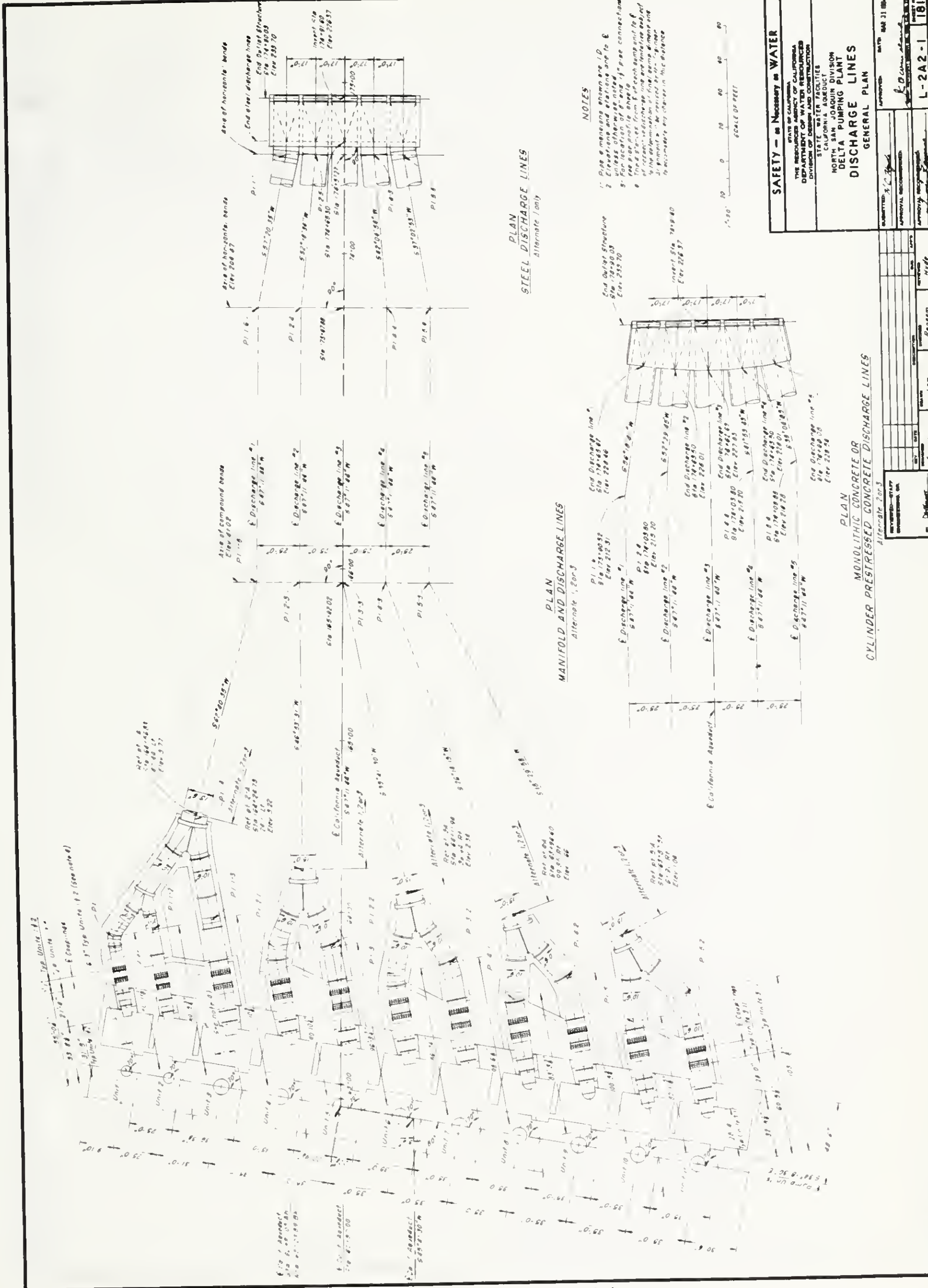

Figure 268. Discharge Lines—General Plan

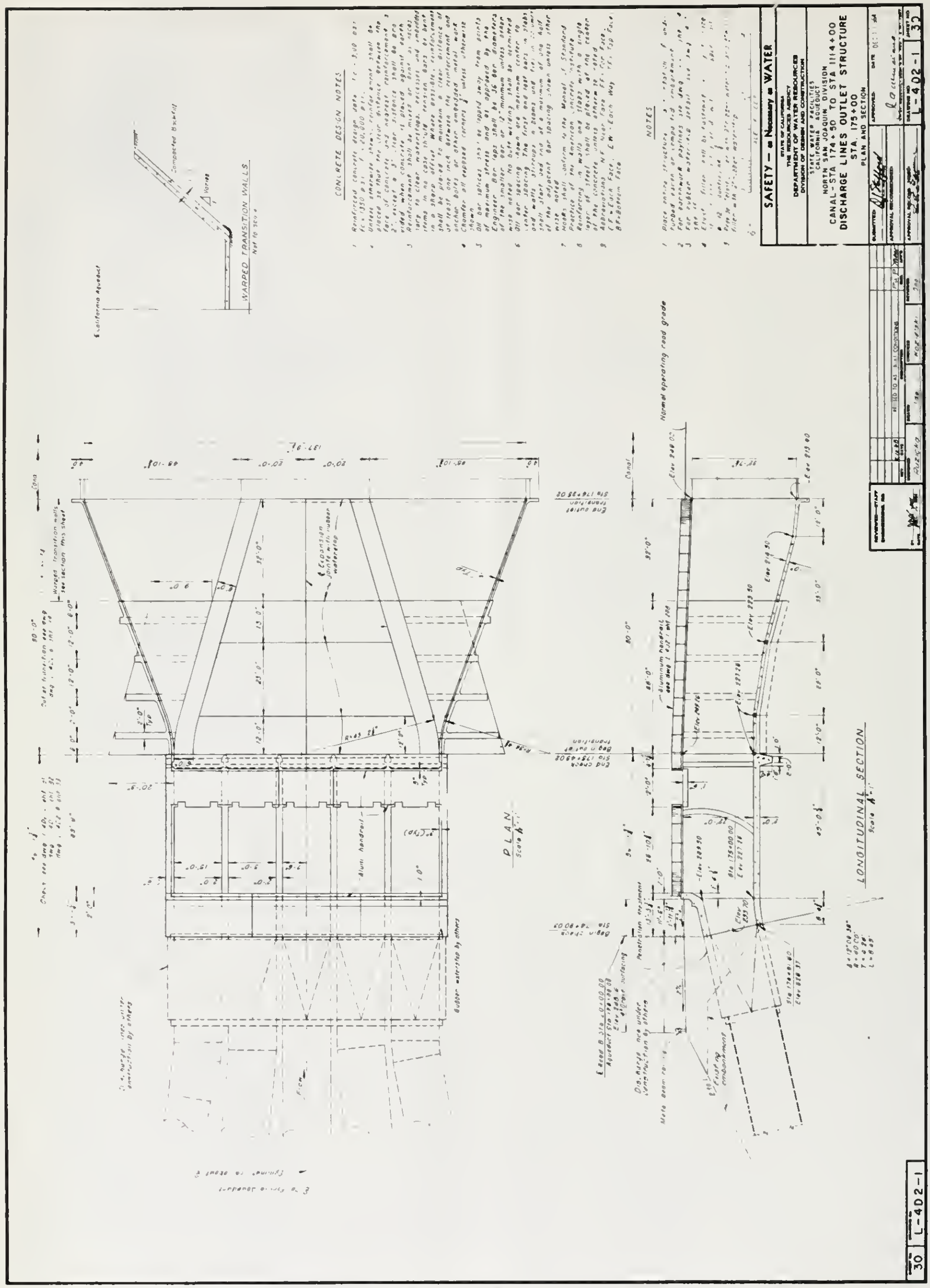

Figure 269. Outlet Structure

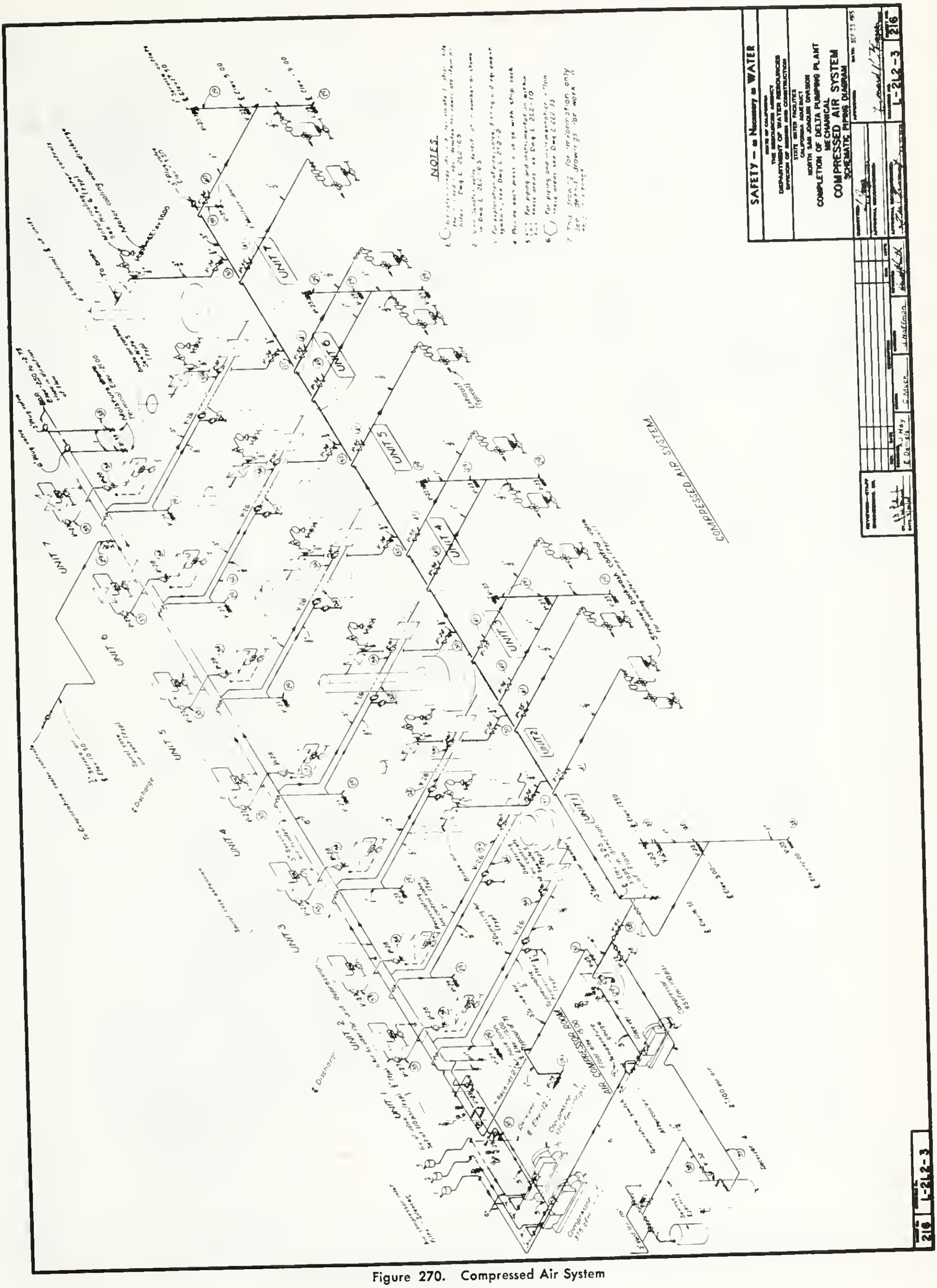

Figure 270. Compressed Air System

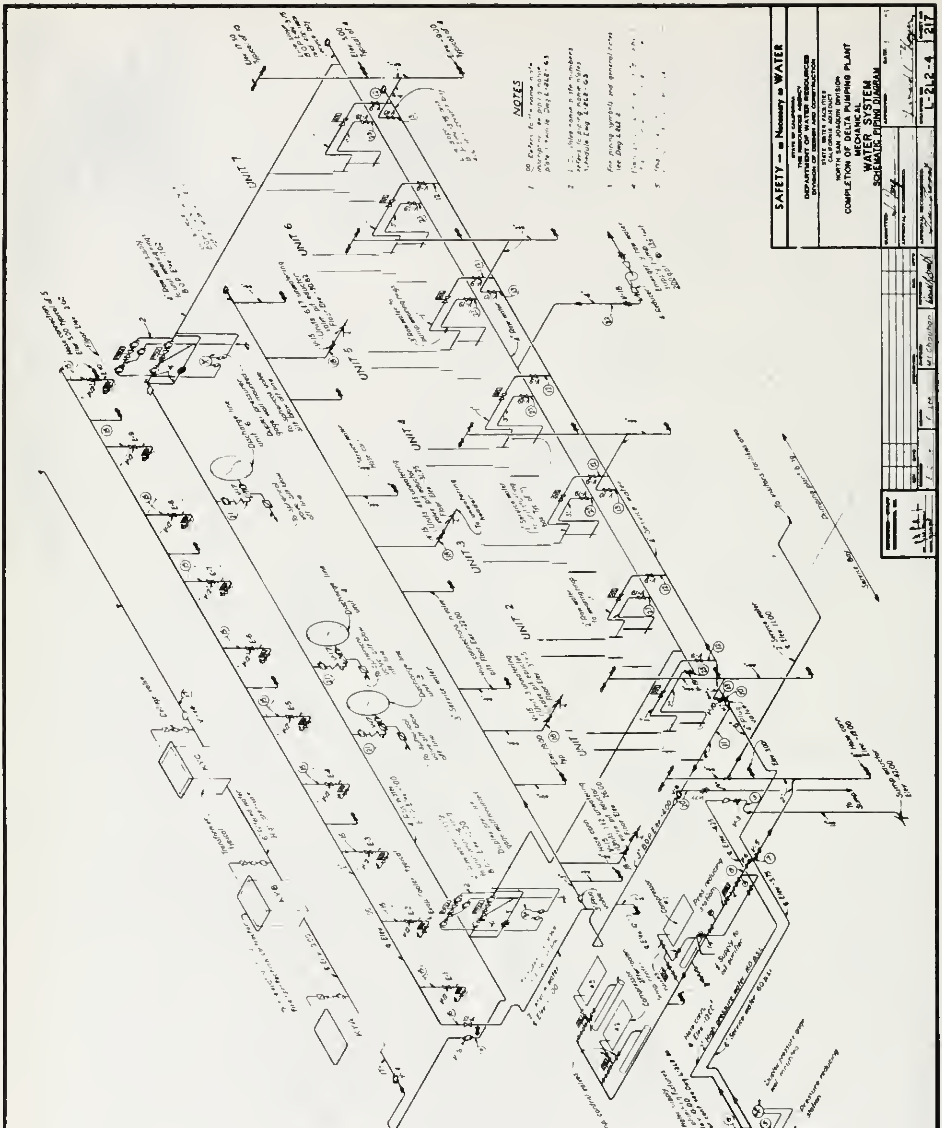

Figure 271. Water System

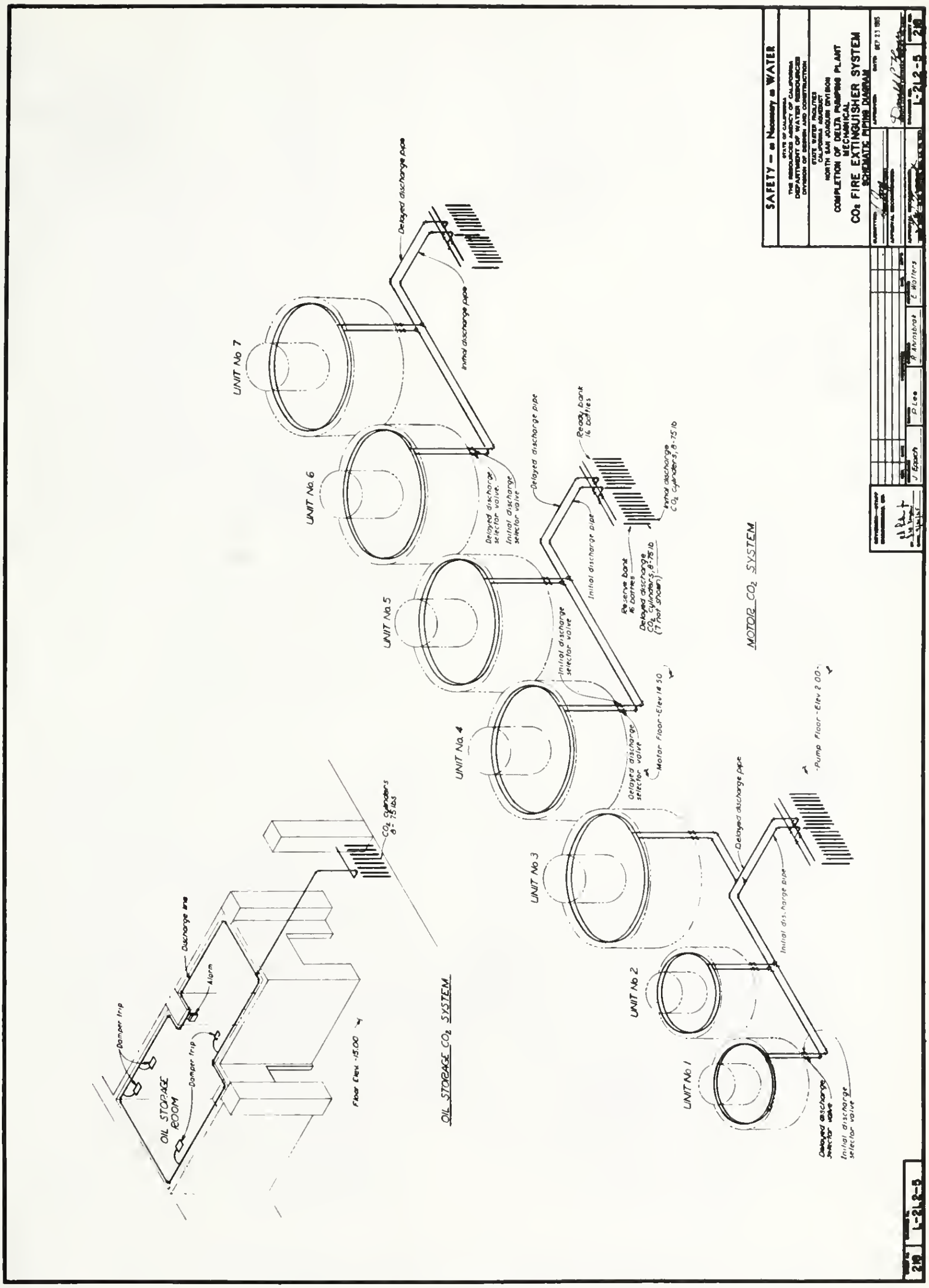

Figure 272. Carbon Dioxide Fire-Extinguisher System

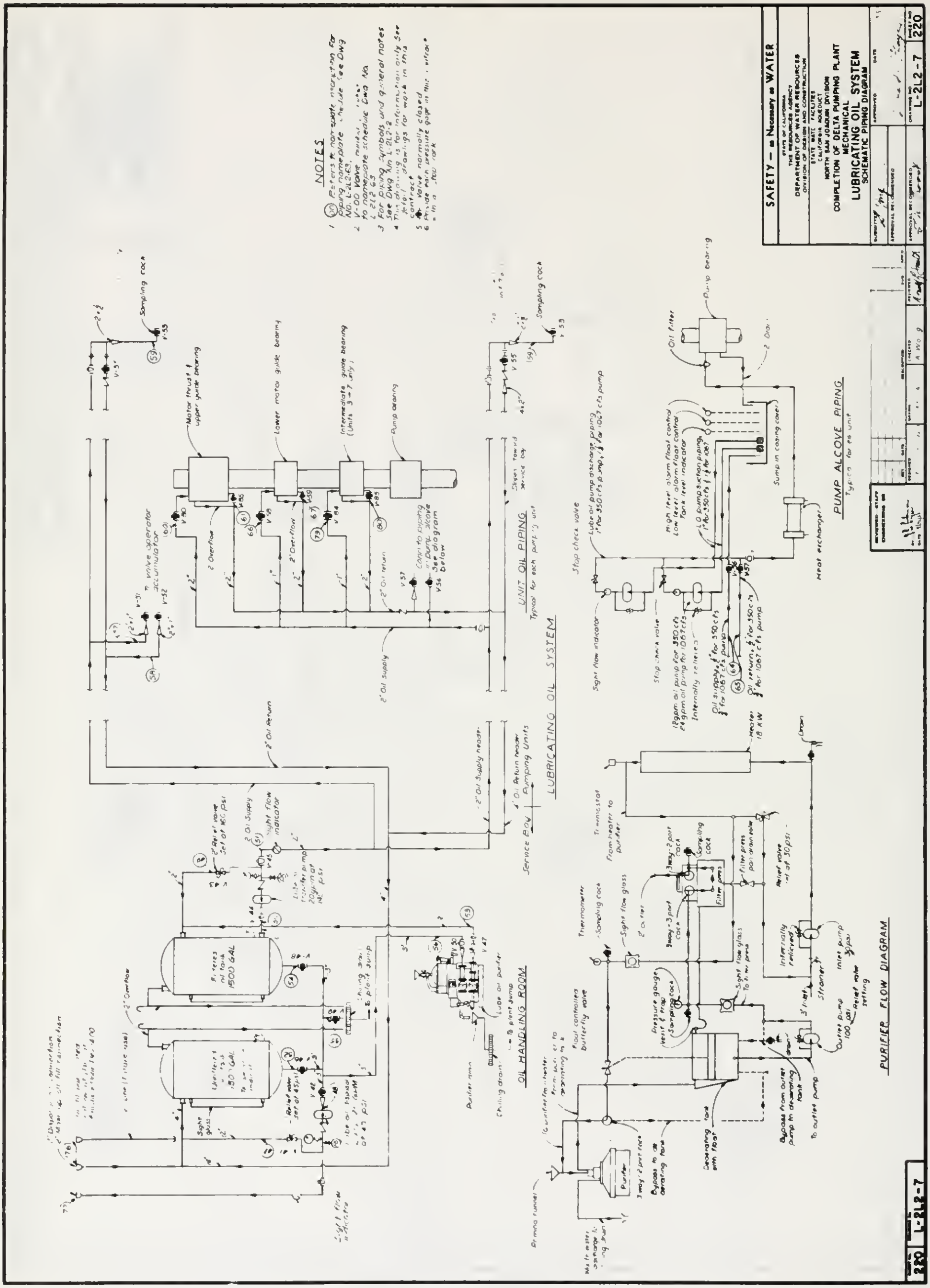

Figure 273. Lubrication Oil System

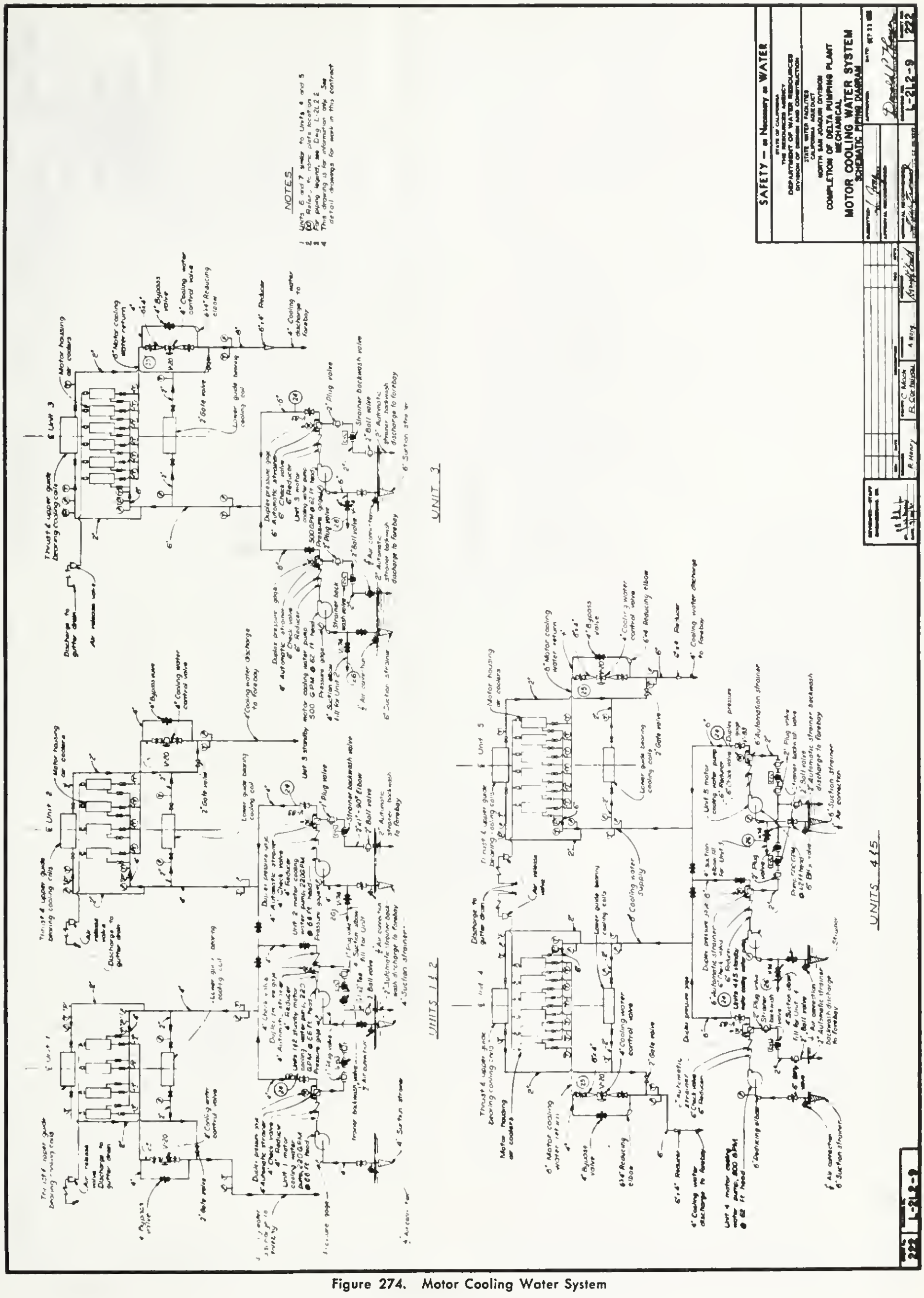

Figure 274. Motor Cooling Water System

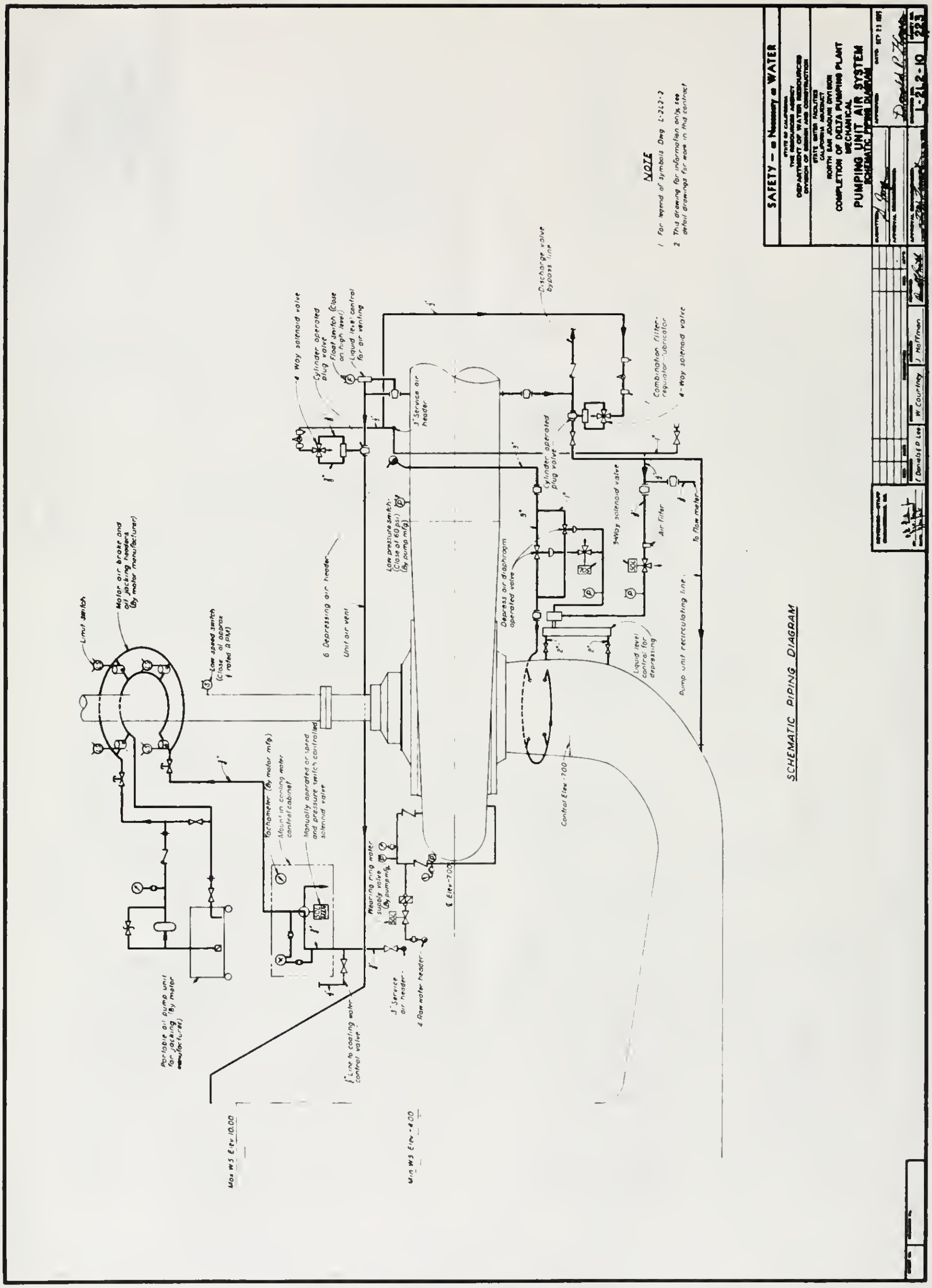

Figure 275. Pumping Unit Air System

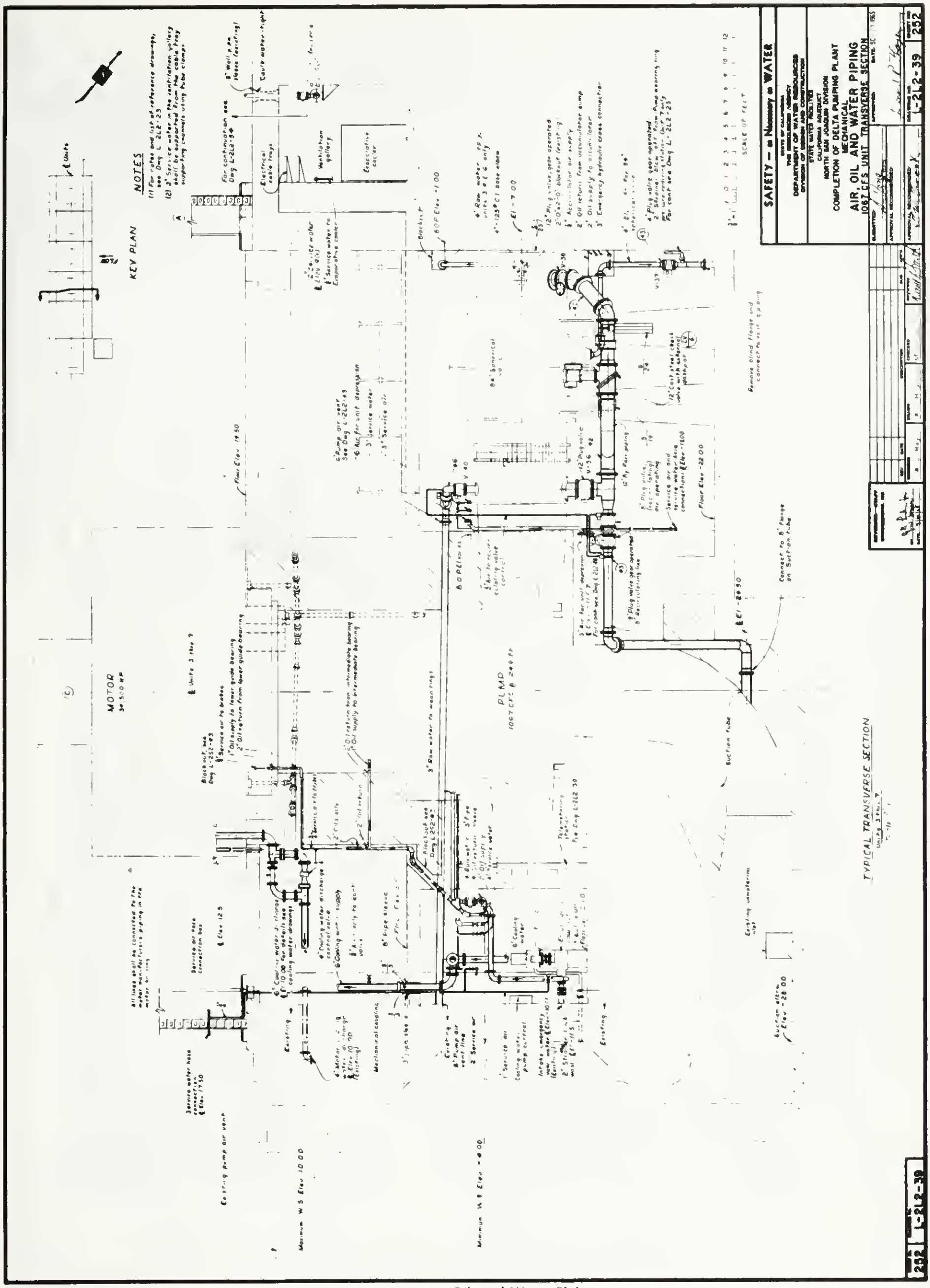

Figure 276. Air, Oil, and Water Piping

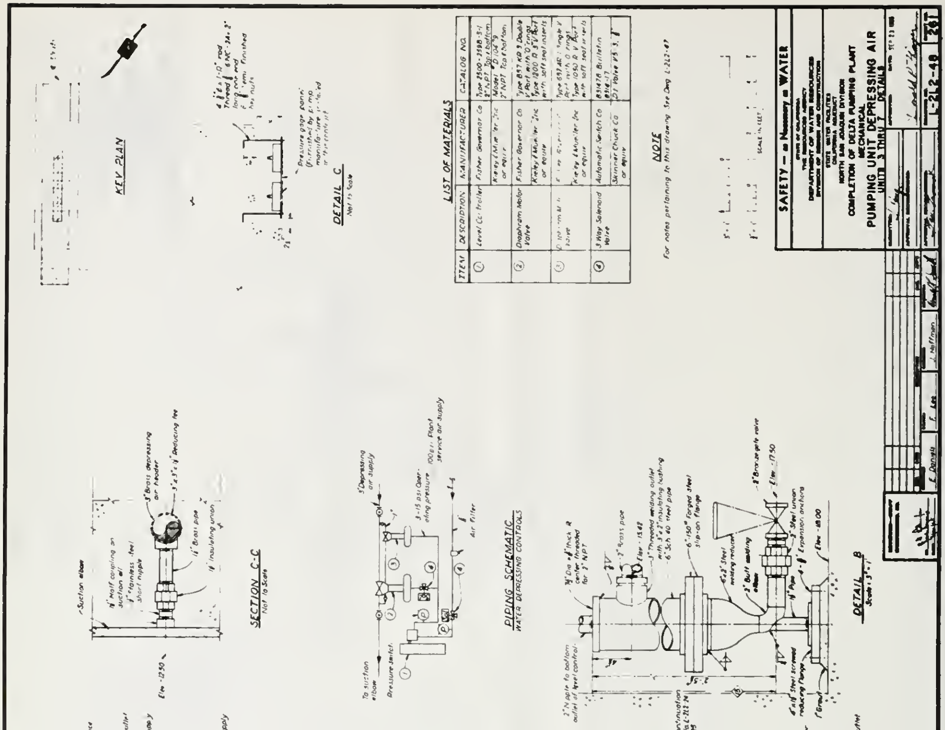

Figure 277. Pumping Unit Depressing Air

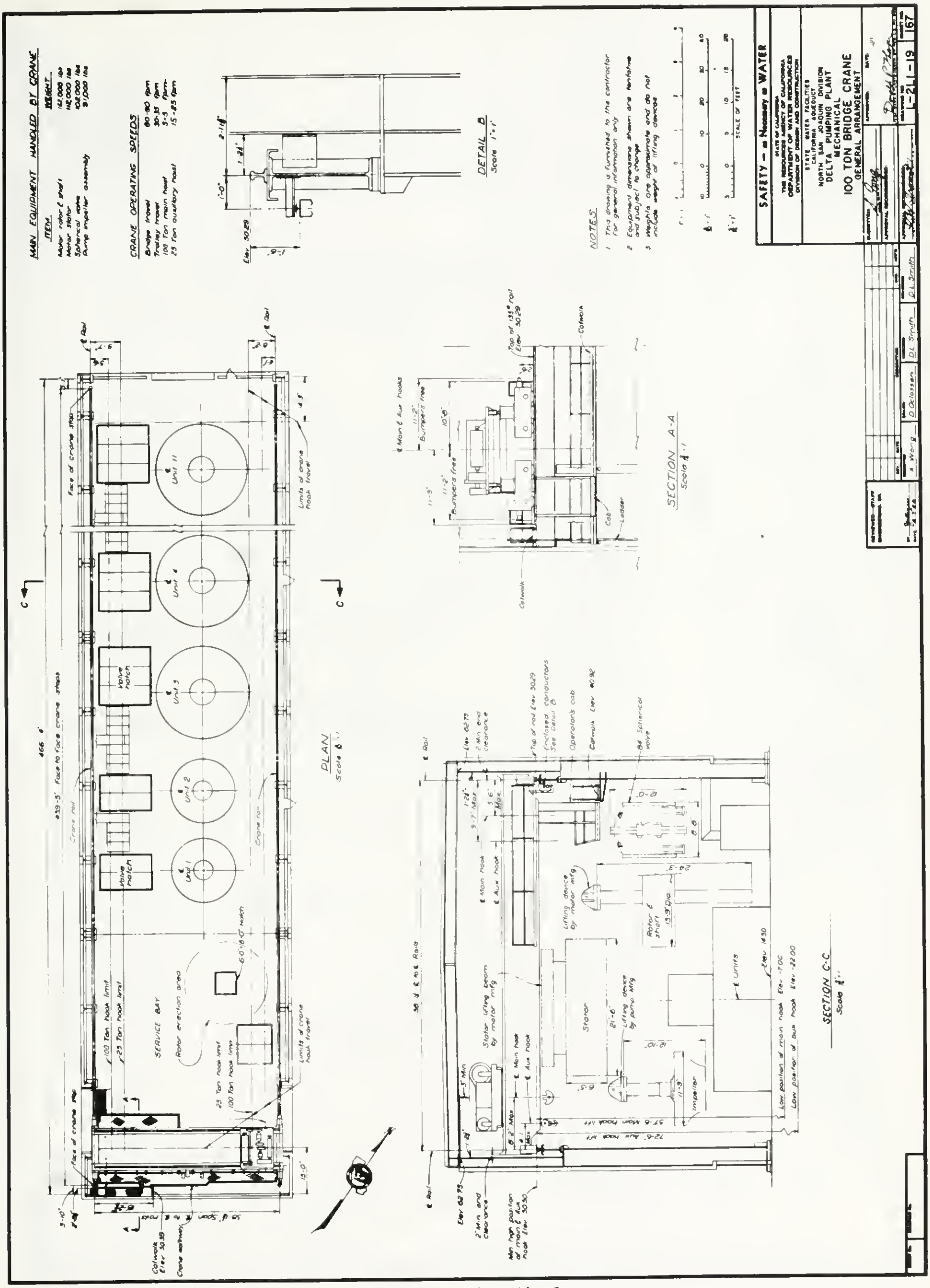

Figure 278. 100-Ton Bridge Crane

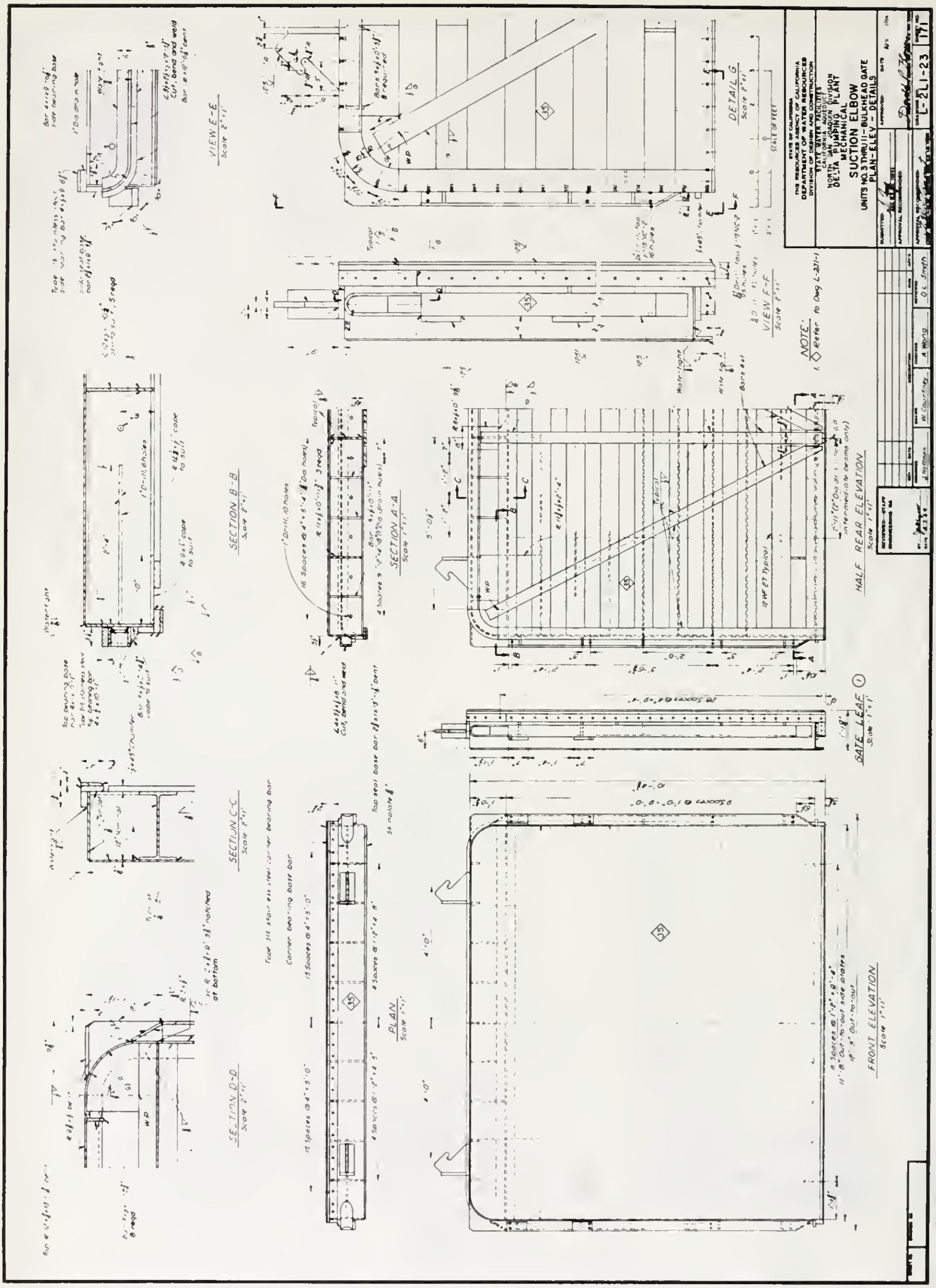

Figure 279. Suction Elbow

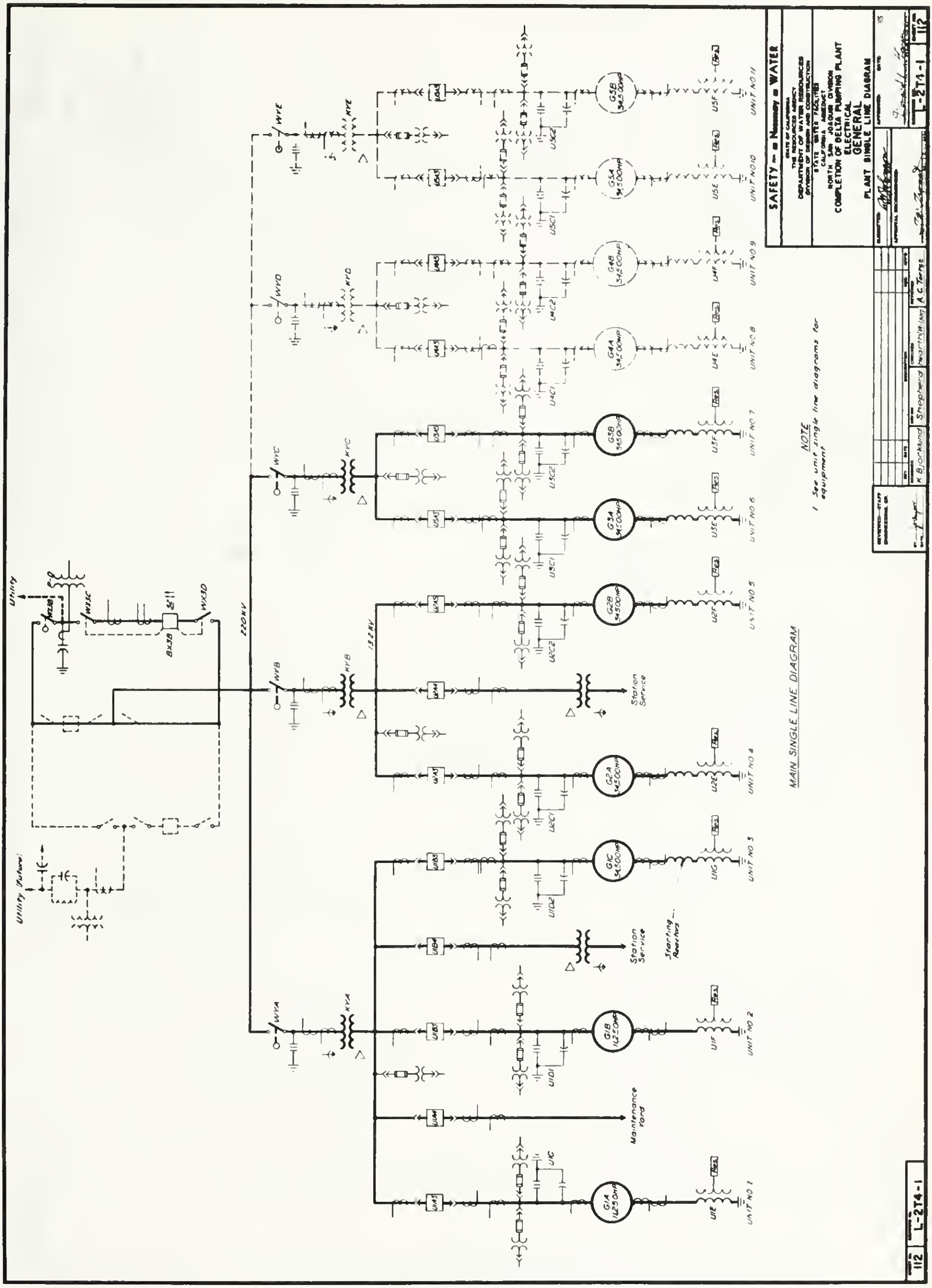

Figure 280. Plant Single-Line Diagram

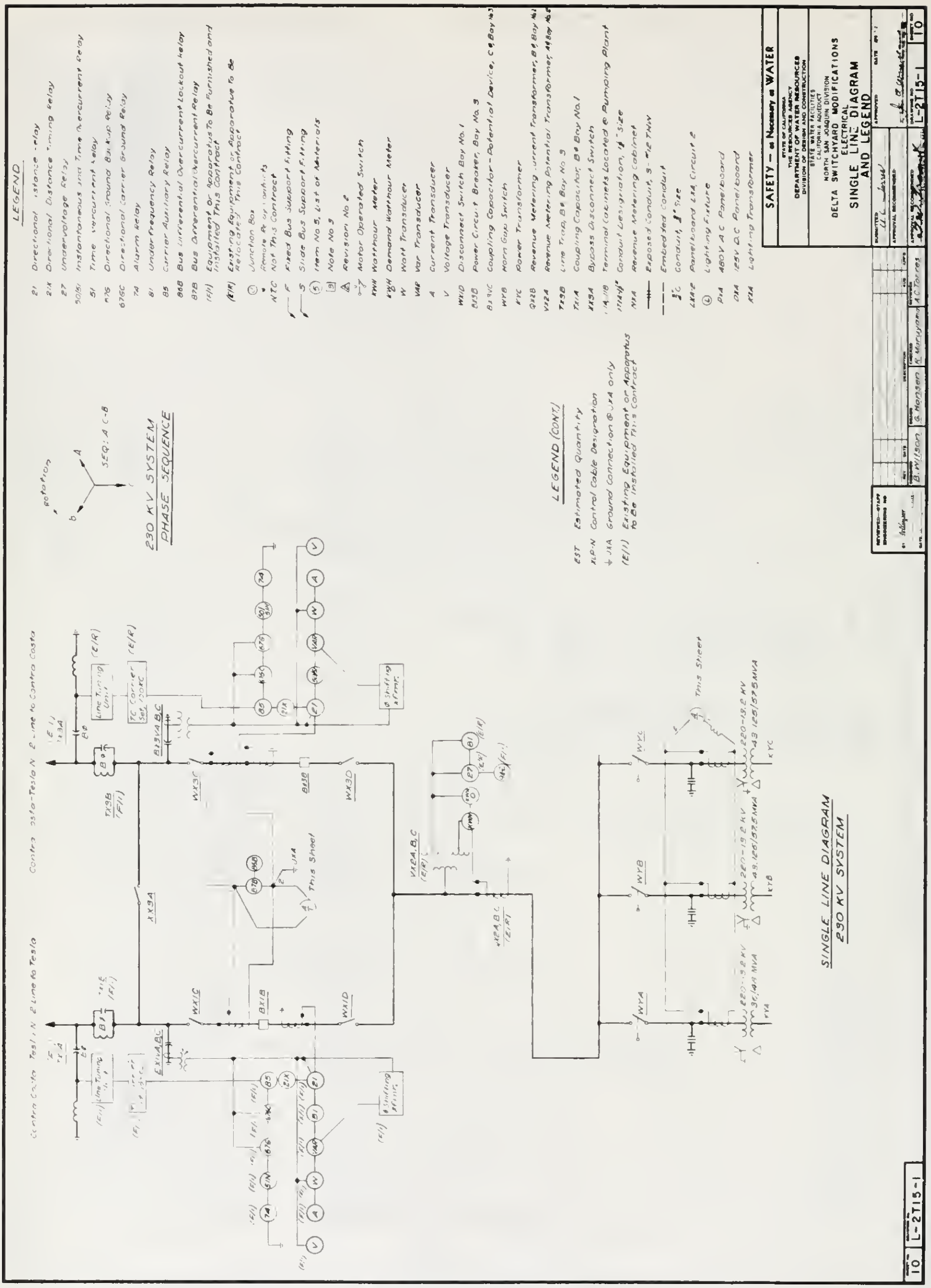

Figure 281. 230-kV Single-Line Diagram

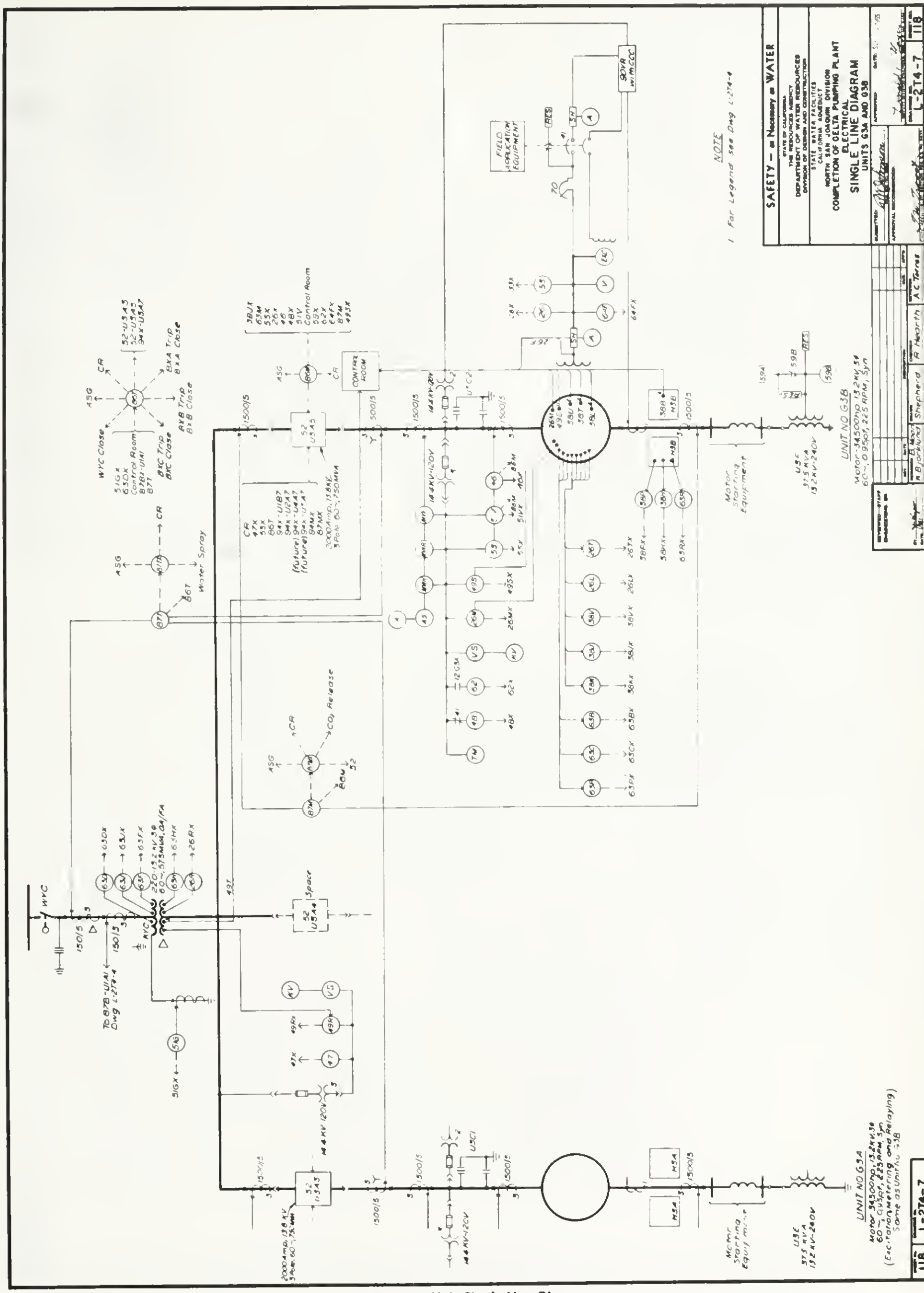

Figure 282. Unit Single-Line Diagram

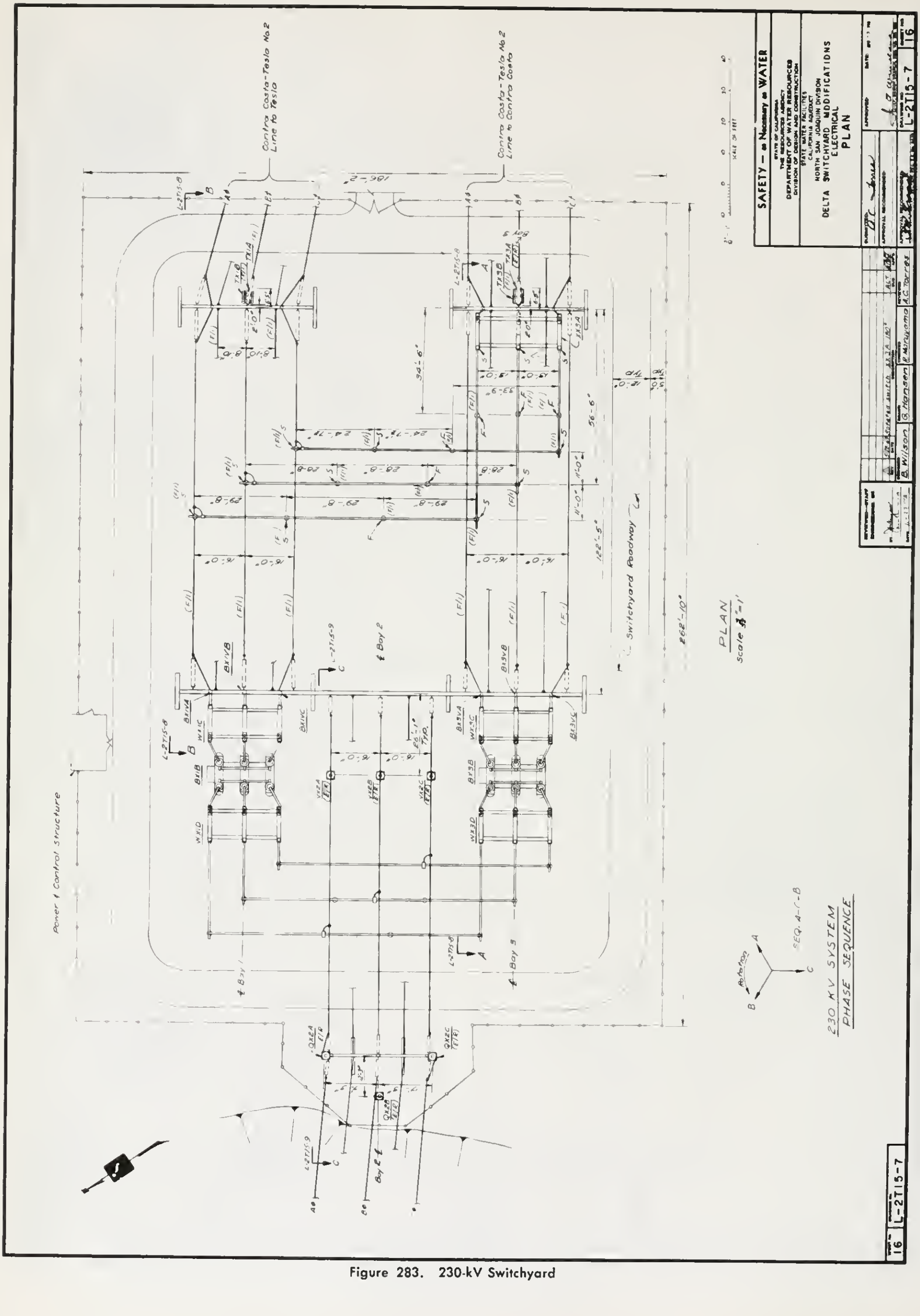

Figure 283. 230-kV Switchyard

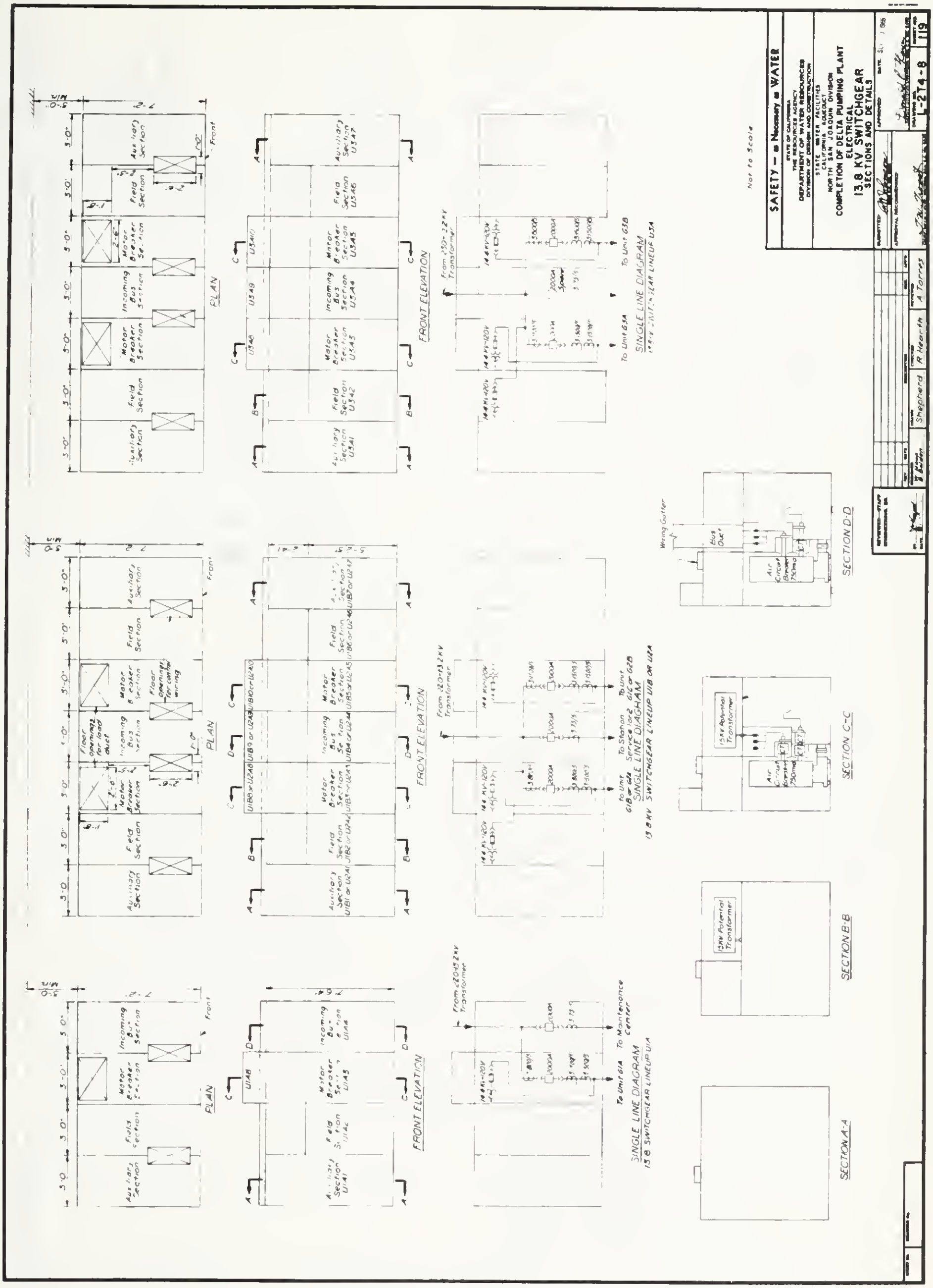

Figure 284. 13.8-kV Switchgear

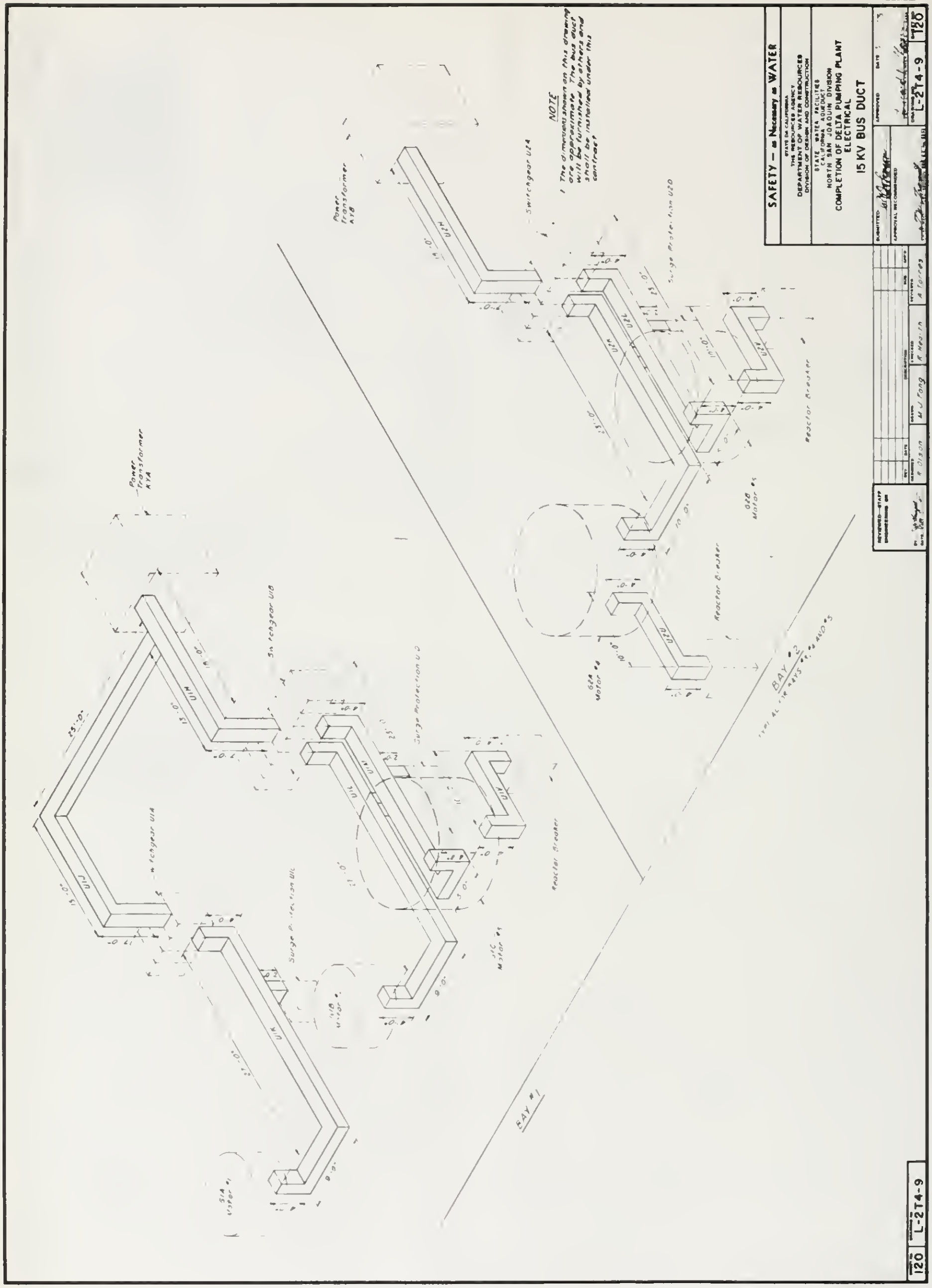

Figure 285. 15-kV Bus Duct

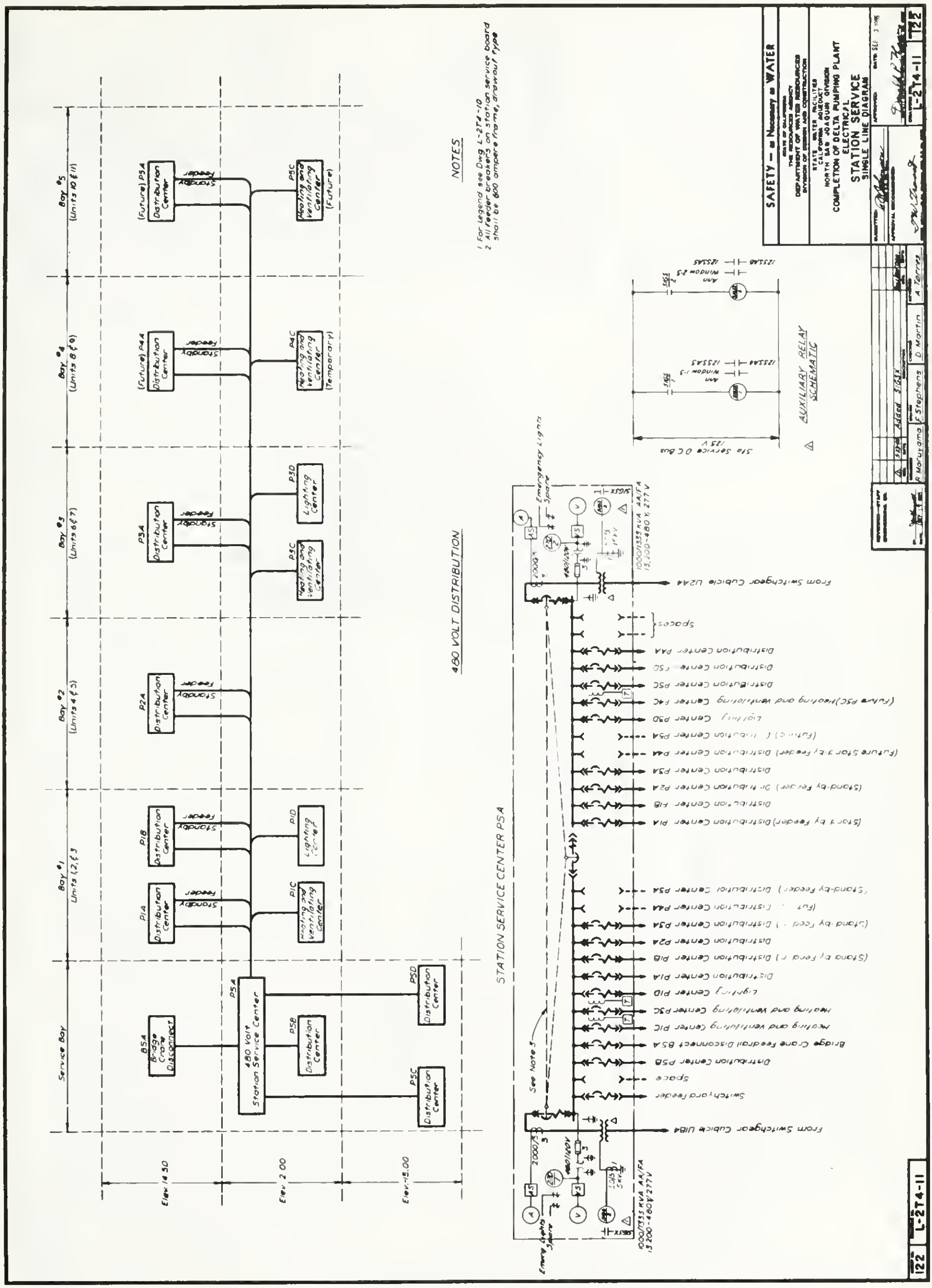

Figure 286. Station Service

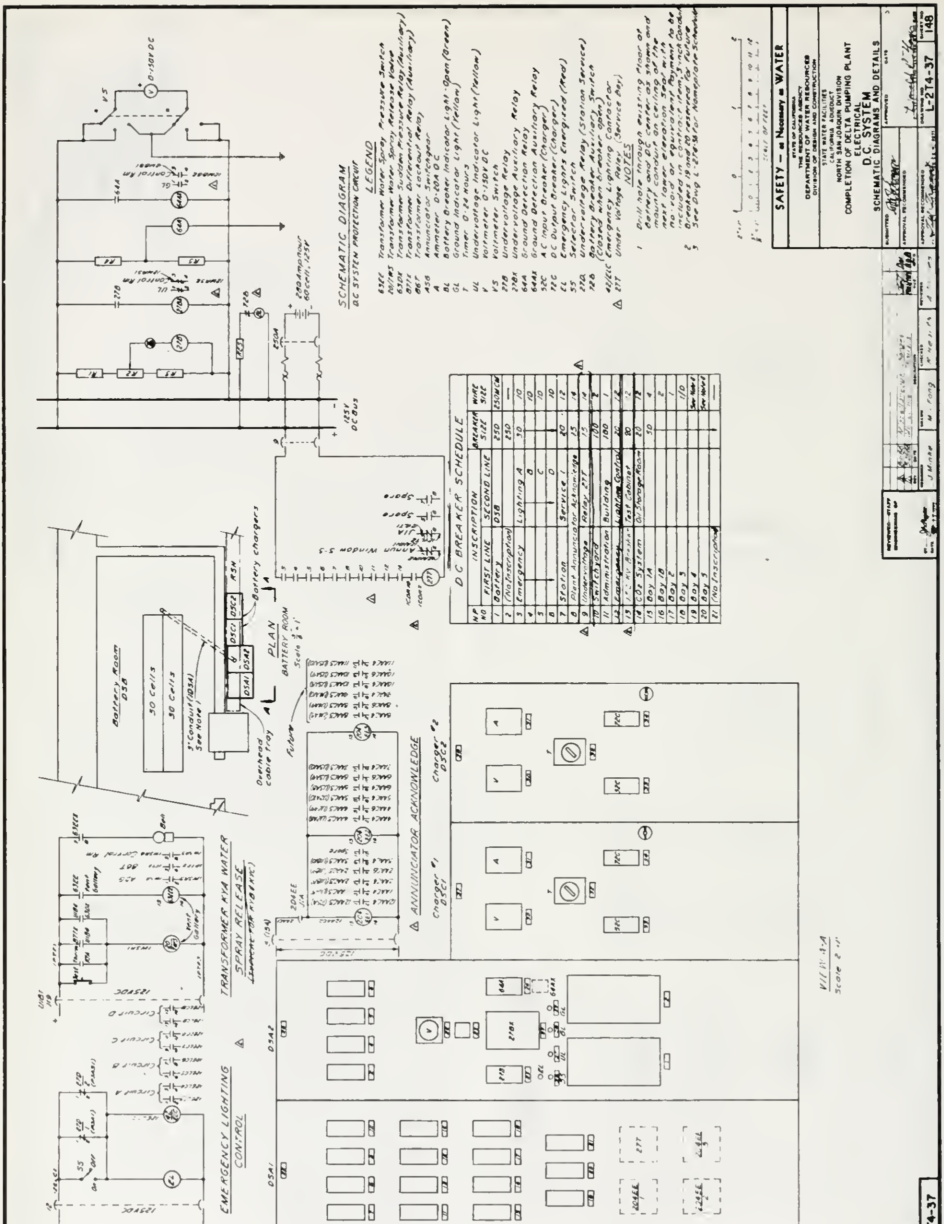

Figure 287. Direct-Current System

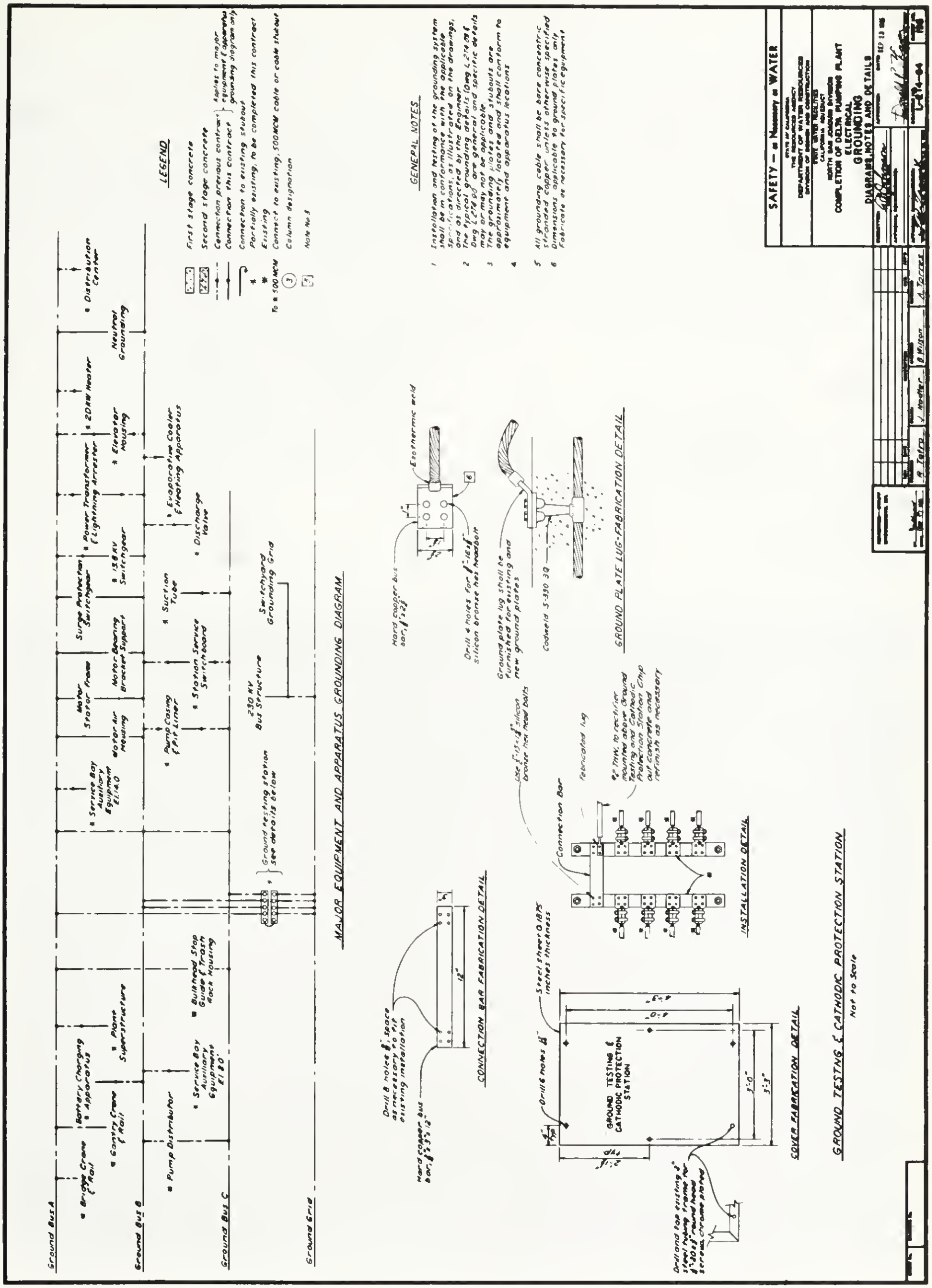

Figure 288. Grounding

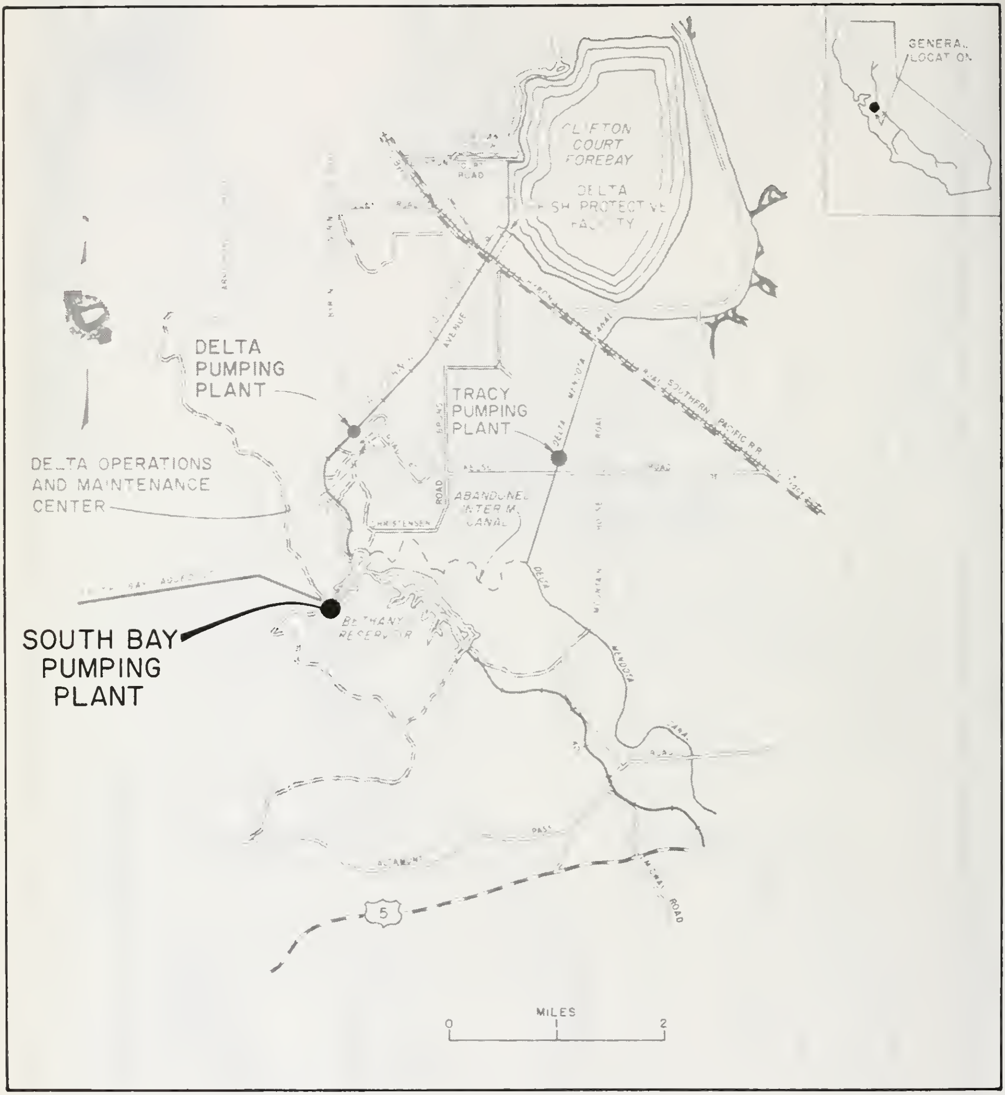

Figure 289. Location Map—South Bay Pumping Plant

CHAPTER V. SOUTH BAY PUMPING PLANT

General

Location

South Bay Pumping Plant is located on the upper end of Bethany Reservoir at the beginning of the South Bay branch of the California Aqueduct. It is in the northeastern corner of Alameda County approximately 4 miles northeast of Altamont and 12 miles west of Tracy (Figures 289 and 290).

Purpose

The plant lifts water from Bethany Reservoir into the South Bay Aqueduct, which serves the water users in the Livermore Valley and south San Francisco Bay area. The conveyance system includes 43 miles of canals, pipelines, and tunnels and terminates at the Santa Clara terminal reservoir (storage tank) near San Jose. This was the first State Water Project pumping plant to be constructed.

Description

This is an indoor plant of reinforced concrete, approximately 226 feet long by 33 feet wide with exterior walls 21 feet in height. It also includes two buried, steel, discharge lines and two steel surge tanks.

The plant contains nine pumping units of three different capacities: one rated at 15 cubic feet per second (cfs) with a 1,250-horsepower (hp) motor, three at 30 cfs with 2,500-hp motors, two at 45 cfs with 3,500-hp motors, and three at 45 cfs with 4,000-hp motors. The 15-cfs unit will be replaced with a 30-cfs unit in the future. Ultimate capacity of the Pumping Plant is 345 cfs with a total combined horsepower of 29,000 and a total design head of 611 feet.

Representative drawings are included at the end of this chapter.

Architectural Design

South Bay Pumping Plant was designed prior to establishment of the State Water Project architectural motif as discussed in Volume VI of this bulletin. However, following construction of the plant, colors and textures were applied to establish some relationship to that motif.

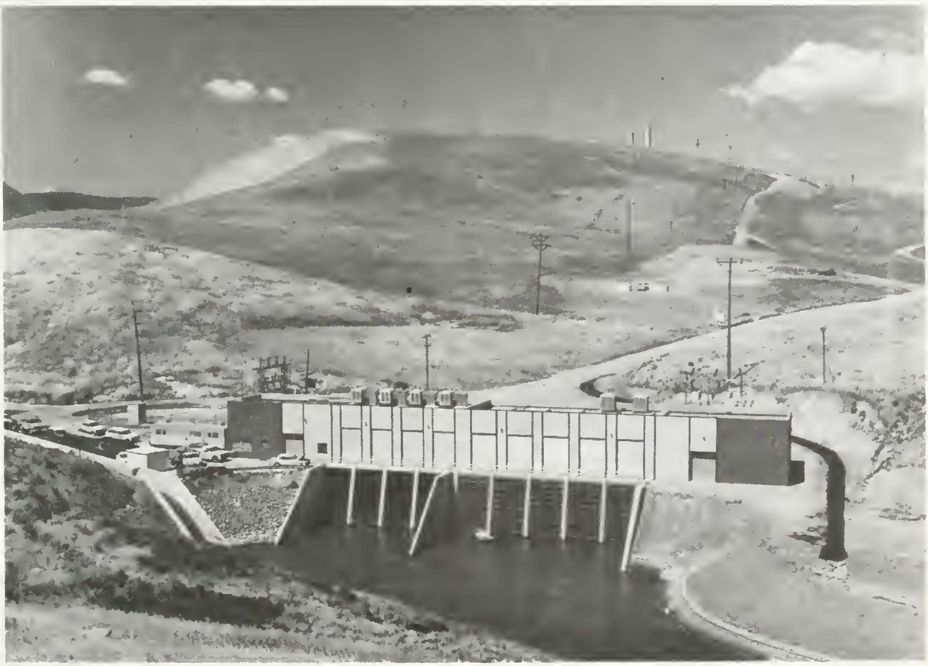

Figure 290. South Bay Pumping Plant

Geology

Site Geology

South Bay Pumping Plant site is on the east flank of the Diablo Range, a mountain range that consists mainly of sedimentary rocks folded into northwest-trending anticlines and synclines. The plant lies on interbedded sandstones and shales of the Cretaceous Panoche formation, which locally dips uniformly at an angle of 19 to 24 degrees to the east. Valley alluvium covers the Panoche in places and consists of Recent deposit of sand, silt, clay, and some gravel.

Geologic Exploration

Exploration consisted of geologic mapping, core drilling, auger drilling, soil and rock testing, and ground water studies.

Instrumentation

Because of the modest size of the plant, no instrumentation was installed.

Seismicity

Major faults in the area include the Calaveras 25 miles west, the Hayward 30 miles west, and the San Andreas 45 miles west.

The area is considered seismically active, and movement of one of the major faults could cause shaking at the plant. The structure could be damaged in the event of a major earthquake.

Civil Features

Preliminary Studies

Preliminary design studies included a two-lift scheme and a one-lift scheme. The one-lift scheme proved to be the most economical and was developed for design and construction. The preliminary studies included the plant structure, mechanical and electrical equipment, discharge lines, and surge tank.

Site Development

Site development included design and construction of access roads to the plant site and surge tank, as well as development of a site drainage system and orientation of the plant structure and switchyard. The plant is situated at the upper end of Bethany Reservoir, and some ditch and channel excavation was necessary to provide an adequate waterway to the plant.

Local runoff is conveyed around the plant area in a reinforced-concrete flume which terminates in a chute-type spillway at the Reservoir. A bridge was provided across the flume for access by landowners and powerline maintenance crews.

Plant Structure

The plant structure was constructed in two stages, the first in 1960 and the second in 1963. The first-stage plant was designed to house four 30-cfs pumping units and their controls, while the second-stage plant was designed for five 45-cfs units. To accommodate the larger motors for the 45-cfs pumps, the structure was made 33 feet wide compared to 27 feet for the first-stage plant. The length of the first-stage plant is 94 feet - 6 inches including a 44-foot service bay, and the length of the second-stage plant is 111 feet - 6 inches, which also includes a 44-foot service bay.

The structure is of reinforced concrete with cast-in-place walls and roof slab. Parapet walls extend 3 feet - 6 inches above the roof slab to provide a barrier for the safety of personnel who are occasionally required to maintain roof-mounted air-conditioning equipment. The substructure is divided by cross walls to form pump pits open to Bethany Reservoir, which serves as the forebay. Each pump is installed in a separate pit.

The plant structure was designed for the usual loads appropriate for this type of structure. One unusual design load considered was 150 pounds per square foot (psf) live load on the roof. The assumed wind load was 15 psf, and the assumed earthquake load was 0.133 times the dead load, applied horizontally.

The plant is founded on the Panoche formation, consisting primarily of sandstone interbedded with laminated shale which tends to slake when exposed to air.

The plant base slab is keyed into the foundation rock at the front and near the back of the plant to provide stability against horizontal sliding.

Waterways

Intake Facilities. The plant is situated at the upper end of the ravine that forms Bethany Reservoir, which is coincident with the California Aqueduct. At the time the plant was constructed and before the Reservoir was filled, the channel into the Pumping Plant was improved by excavating material from the ravine and placing riprap on the slopes adjacent to the plant structure.

The pump pits are open to the forebay and are provided with trashracks and stoplogs. The trashracks span vertically with bars spaced to provide 3-inch-wide openings. The stoplogs were fabricated of structural steel with a steel skinplate and rubber seals. They can be installed in any of the pump pits and are stored in the yard when not in use.

Pump Discharge Systems. The nine South Bay pumps discharge water through two parallel, buried, discharge lines approximately 4,010 feet long to the eastern ridge of the Diablo Range. Water flows by gravity through the remaining reaches of the South Bay Aqueduct.

The pump discharges from Pumps Nos. 1, 2, 3, and 4 are combined by a manifold into the 54-inch-diameter south discharge line. This discharge line was designed to convey 120 cfs with a total dynamic head of 611 feet. A second manifold combines pump discharges from Pumps Nos. 5, 6, 7, 8, and 9 into the 66-inch-diameter north discharge line (Figure 291).

Figure 291. North Manifold

This discharge line was designed to convey 225 cfs with a maximum dynamic head of 619 feet.

Each discharge line terminates at a surge tank. The south tank is 13 feet in diameter and 94 feet high. The north tank is 17 feet in diameter and 104 feet high.

Each surge tank is equipped with an inflow riser pipe that separates flow in the discharge line from that in the connecting Brushy Creek Pipeline. This separation, in the event of a sudden cessation of pump flow due to power failure, limits the reverse flow through the pumps. The surge tanks also provide sufficient storage to contain the resulting surges in Brushy Creek Pipeline without allowing column separation at the high points along the Pipeline.

Many features of these discharge lines have been designed in accordance with criteria described in Chapter I of this volume.

There are six components of each pump discharge system at South Bay Pumping Plant: (1) discharge carrier pipes, (2) manifold, (3) pump discharge line, (4) discharge flowmeter, (5) surge tank, and (6) appurtenances.

South Pump Discharge System

Discharge Carrier Pipes. Four 24-inch-diameter pump discharge carrier pipes connect to the manifold wye branches. Each carrier pipe was installed inside a length of 32-inch casing pipe and is equipped with two insulating sleeve couplings which insulate it from the manifold and pump discharge pipe. The carrier pipe also is insulated from the casing pipe. End seals prevent entry of backfill material between the two pipes while allowing them to move independently. This arrangement allows for settlement of backfill and for differential settlement between the manifold header and the pumping plant.

Manifold. Each set of carrier pipes converges in a 24-inch by 36-inch wye. The resulting 36-inch-diameter pipes converge in a 36-inch by 54-inch wye. The 24-inch wyes were designed with a two-plate reinforcement system and the 36-inch wye has three-plate reinforcement. The three wyes are encased in a concrete anchor block.

Pump Discharge Line. The 54-inch-diameter, buried, discharge line is welded steel pipe with plate thickness varying from $\frac{3}{8}$ to $\frac{11}{16}$ of an inch. ASTM A285 Grade C, firebox quality steel having a yield stress of 30,000 pounds per square inch (psi) was used. The allowable design stress of 13,500 psi is based on a factor of safety of 2 and 90% weld efficiency.

Steel pipe required cathodic protection and corrosion control monitoring. Soil resistivity tests conducted along the alignment indicated that the soils are severely corrosive. Of the two most common types of coatings, coal-tar enamel was specified instead of cement mortar because it was more economical. Protection from internal corrosion was required because of the quality of the waters to be conveyed. Lining of coal-tar enamel also was specified for reasons of economy.

Provisions for cathodic protection and corrosion control monitoring were established in the following manner:

1. An anode bed, consisting of seven duriron anodes, was installed near the lower end of the surge tank access road to provide cathodic protection for the discharge line. A 4-kV power line was installed underground from the Pumping Plant to a riser pole near the anode bed to supply power for the cathodic protection rectifier. The system was activated when the north discharge line was installed.
2. Corrosion test stations were installed along the discharge line at approximately 500-foot intervals to monitor corrosion and cathodic protection.
3. Sections of pipe to be embedded in concrete anchor blocks and thrust blocks were coated with coal-tar epoxy.

Flowmeter. A remote reading flowmeter is located along the 54-inch discharge line to monitor flow in the South Bay Aqueduct. The meter consists of a modified Venturi flow tube connected to a differential pressure-type recorder and transmitter and is housed in a reinforced-concrete vault.

Surge Tank. The surge tank is a 94-foot-high welded steel tank, 13 feet in diameter, with the pump discharge line rising vertically inside the tank to within 21 feet of the top. The tank was designed to prevent water column separation in Brushy Creek Pipeline in the event of sudden pump shutdown and to relieve transient pressures in the discharge lines.

A 90-degree bend in the discharge line is embedded in the concrete footing of the tank. However, the tank outlet pipe is welded to the tank sidewall near the tank base. Both inlet and outlet pipes are articulated at the base of the tank by short pipe spools installed in the lines with insulating-type sleeve couplings.

Steel plate in the tank varies from $\frac{5}{16}$ to $\frac{3}{8}$ of an inch, while that in the riser pipe varies from $\frac{3}{8}$ to $\frac{11}{16}$ of an inch. The tank was designed in accordance with Uniform Building Code requirements for loads due to contained water, wind, and earthquake.

The tank interior is coated with coal-tar epoxy resin and is further protected by a cathodic protection system that utilizes magnesium anodes mounted on the interior of the tank. The exterior surface of the tank is coated with red-lead primer and phenolic-resin aluminum paint.

Appurtenances. Entry into the discharge line is provided at 1,000-foot intervals by buried manholes installed at the top of the pipe. An access manhole and a 6-inch blowoff control valve are located in a concrete vault near the junction of the manifold and the discharge line. The blowoff discharges into No. 4 pump sump.

North Pump Discharge System

Discharge Carrier Pipes. Five 30-inch-diameter, discharge, carrier pipes extend from the back of the plant similar to those on the south pump discharge system. They also are installed in casing pipes; however, only one sleeve coupling is located on each pipe.

Manifold. The carrier pipes are manifolded to the 66-inch discharge line. The manifold header diameter expands in two steps: 30 to 52 inches, and 52 to 66 inches. The manifold is encased in a buried, concrete, anchor block (Figure 291).

Pump Discharge Line. The north discharge line was designed to convey 225 cfs at a velocity of approximately 9.5 feet per second (fps) and a hydraulic gradeline slope of 0.004. Three alternate designs afforded bidders an option. The alternative adopted consisted of 800 feet of 67-inch steel pipe (ASTM A441) and 3,200 feet of 66-inch, prestressed-concrete, cylinder pipe. Steel pipe was installed at the plant end of the discharge line and was mortar-lined and coal-tar enamel-coated.

For corrosion protection, the discharge line was installed with insulating couplings and test stations at the plant, the surge tank, and the junction of the steel and the prestressed pipe. Corrosion test stations were installed at intervals of 500 to 1,000 feet along the prestressed pipe.

Flowmeter. A remote reading flowmeter installation is located on the discharge line similar to that installed on the south discharge line.

Surge Tank. The north surge tank was constructed adjacent to the south (first-stage) surge tank and is of similar design. The tank has an inside diameter of 17 feet and a height of 104 feet. Inlet and outlet pipes make 90-degree bends in the anchor block and enter the tank through the floor plate. The outlet provides complete drainage of the tank through Brushy Creek Pipeline and also allows the pipe to flow full until the tank is drained. Due to the position of the outlet, the inlet riser pipe is located off-center in the tank and is braced at the top with angles welded to the tank wall. A 3-foot-wide steel-grating walkway with an interior handrail is provided around the tank circumference,

Figure 292. Surge Tank

3½ feet below the top of the tank. The tank exterior is equipped with a welded steel ladder enclosed in a safety cage and an access manhole near the tank base (Figure 292).

Appurtenances. One manhole located in a concrete pipe access well was installed at the manifold and one at the surge tank. One additional buried manhole is located halfway up the discharge line. An 8-inch, steel-pipe, blowoff line extends from the bottom of the manifold and terminates in a "Krueter Brake"-type dissipator in the No. 6 pump sump. This blowoff is an improvement over the south blowoff since it allows complete dewatering of the discharge line and manifold without throttling of the blowoff valve.

Mechanical Features

General

The mechanical installation includes nine pumps, nine discharge valves, and auxiliary equipment.

Chapter I of this volume contains general information for all plants in the State Water Project. Information which is unique to South Bay Pumping Plant is included in the following:

Equipment Ratings

Pumps

Manufacturer:	Pumps Nos. 1 and 2— Fairbanks-Morse, Inc.	
	Pumps Nos. 3 and 4— Peerless Pump Co.	
	Pumps Nos. 5 through 9— Johnston Pump Co.	
Type:	Vertical-shaft, multistage, vertical-turbine, centrifugal	
Pump No. 1		
Discharge:		15 cfs
Total Head:		611 feet
Speed:		1,200 rpm
Horsepower (motor rating):		1,250
No. of pump stages:		6
Pumps Nos. 2, 3, and 4		
Discharge, each:		30 cfs
Total Head:		611 feet
Speed:		900 rpm
Horsepower (motor rating), each:		2,500
No. of pump stages:		5
Pumps Nos. 5, 6, and 7		
Discharge, each:		45 cfs
Total Head:		611 feet
Speed:		900 rpm
Horsepower (motor rating), each:		4,000
No. of pump stages:		4
Pumps Nos. 8 and 9		
Discharge, each:		45 cfs
Total Head:		611 feet
Speed:		900 rpm
Horsepower (motor rating), each:		3,500
No. of pump stages:		4

Pump Discharge Valves

Manufacturer:	Units Nos. 1 through 4— Baldwin-Lima-Hamilton Corp.
	Units Nos. 5, 6, and 7— Darling Valve Manufacturing Co.
	Units Nos. 8 and 9— Crane Co.
Type:	Units No. 1 through 7— Spherical, single, fixed-seat
	Units Nos. 8 and 9— Tapered plug cone
Design Pressure:	400 psi
Operating Time:	Two-speed adjustable, set 5 sec. fast, 45 sec. remaining
Operating System Pressure:	Units Nos. 1 through 4— 200 psi
	Units Nos. 5 through 9— 500 psi

Pumps

The pumps are multistage, vertical-turbine, centrifugal type, directly connected to vertical synchronous motors. They are suspended from the motor base plates and have 90-degree discharge elbows approximately 4 feet below the motor room floor. Units Nos. 1 through 4 are manifolded to one discharge line and Units Nos. 5 through 9 to a second discharge line.

They were purchased and installed beginning in 1960, with Units Nos. 1 and 2 operational in May 1962 and completion of installation of Units Nos. 5 through 9 early in 1969. This phased procurement of pump units was designed to match capital outlay with the scheduled buildup of water deliveries from South Bay Aqueduct.

The pumps have cast-iron bowl assemblies, fabricated steel columns, water-lubricated bearings, and bronze impellers. Other features include stainless-steel shafting, and bronze and stainless-steel wear rings. The weight of the rotating parts and the hydraulic downthrust are carried by Kingsbury thrust bearings located in the motors.

The pumps are started watered against closed discharge valves. Air is released through air release valves to allow water to reach the packing boxes and water-lubricated bearings within a few seconds after startup.

Pump Modifications

Extensive pump modifications were necessary after installation of the first six units. During the period 1963 to 1966, pump shafts failed in four of the units, and cracks in the pump columns were discovered at the discharge elbows. An extensive investigation, involving field testing, design analysis, and laboratory testing, showed that the large hydraulic thrusts at the pump discharge elbows were causing distortion and horizontal movement of the pump columns. This resulted in once-per-revolution stress reversals and eventual fatigue failures of the shafting.

Modifications of the pumps included replacing the existing shafts with precipitation-hardened stainless-steel shafts, providing welded reinforcement for the pump discharge elbows and motor base plates, adding adjustable steel plates behind the discharge elbows to accommodate the large hydraulic thrusts, and adding tie rods at the lower end of the pump columns to restrain column movement.

The modifications have proven successful, and no serious problems have occurred in operation of the pumps since the modifications were made in 1967. The last three units to be installed, Units Nos. 5, 6, and 7, had the additional features incorporated in their original design.

Pump Discharge Valves

A fixed, single-seat, spherical valve is located on the discharge side of Pump Units Nos. 1 through 7. Units

Nos. 8 and 9 have tapered plug-cone valves on the pump discharge. They are used as shutoff valves to prevent backflow through the units when they are started and stopped and to isolate each pump from its discharge line for inspection and maintenance. The valves are operated only in their fully open positions during normal pumping.

They are operated by double-acting hydraulic cylinders. The operators for valves on Units Nos. 1 through 4 are actuated by oil from a 200-psi hydraulic system, while valve operators for Units Nos. 5 through 9 are actuated by a 500-psi hydraulic system. Each of the two systems is the air-over-oil type and includes these features: oil accumulator; oil reservoir and pumps; air compressor; directional and flow control valves; control panel; and piping, wiring, and instruments. In addition, each system includes a bank of nitrogen cylinders to provide pressurization for the system if a compressor or other air system failure occurs.

Each valve opens and closes with a two-speed sequence, controlled by a cam-operated pilot valve attached to the discharge valve's main shaft. The rate of discharge valve movement is controlled by metering valves which restrict the rate of oil flow back to the oil reservoir.

Equipment Handling—Crane

Installation and removal of major equipment, including pumps, motors, and valves, is by mobile crane furnished by local crane and rigging companies. A 60-ton, minimum-capacity, mobile crane is required to lift the 20-ton maximum load because of the boom angle required to clear the plant structure. The equipment is handled through removable hatches in the plant's roof.

The decision to utilize mobile crane service in lieu of a permanent crane was based on economic considerations determined during the initial design stage. Since that time, however, additional factors have necessitated a reevaluation of that initial study. These factors are: (1) costs for mobile crane service have increased greatly since plant construction, (2) two accidents have occurred due to slipping of mobile crane outrigger pads, and (3) in-plant service of equipment is impractical with mobile crane service because of the high hourly costs and the lack of precise control capabilities.

It is anticipated that permanent crane service may be added in the future. This crane would be a 20-ton, outdoor, gantry type, straddling the plant. Addition of a bridge crane or roof-supported gantry is not feasible because of the extensive structural modifications required to permit the plant to support the additional load.

Surge Control

Pressure surges caused by electrical service interruptions are alleviated by discharge valve closing speed control and by surge tanks located at the high points of the two discharge lines. Valve closing speed is approximately 5 seconds for the first and largest portion of the closing sequence and approximately 45 seconds for the remaining portion, until the valve is seated.

Auxiliary Service Systems

The compressed air, raw water, drainage, dewatering, plumbing, and sewage systems and the water-level equipment are described in Chapter I of this volume.

Air conditioning for this plant was not considered necessary. Roof-mounted evaporative coolers were installed to provide some degree of cooling; however, problems with equipment temperature, corrosion of electrical contacts, and extensive maintenance required to keep the evaporative coolers functioning properly have led to a reconsideration of the initial concept. Refrigerated air conditioning will be added to parts of the plant.

Electrical Features

General

The electrical installation includes motors, switchgear, and auxiliary systems for station service and protection of equipment and personnel. Information contained in Chapter I of this volume is not directly applicable to this plant since it is not typical of the major plants of the State Water Project.

Description of Equipment and Systems

Essentially, there are two independent electrical systems. These independent systems resulted from the extremely rapid increase in water requirements over those which were originally anticipated. Units for the first half were added, and the second half of the total plan was constructed within the span of a few years. Normally, a single power supply and station service system would have been installed rather than the two independent systems.

The nine motors are operated from their 4,160-volt supply (Figure 293). They are started full-voltage with water in the pump casing. The motors are wye-connected, with neutrals solidly grounded. Three power transformers at the plant reduce voltage from 60 kV to 4,160 volts to supply the motors and station service systems. Transformers and high-voltage protection equipment are owned and maintained by the utility company (Figure 294). Ownership of the switchyard by the utility company is unique to this plant and resulted in an economic advantage to the Department of Water Resources through the power rates. Circuit breakers are used to operate and protect the motors and station service transformers. Lightning arresters and capacitors on the 4,160-volt bus protect the equipment from lightning or switching surges.

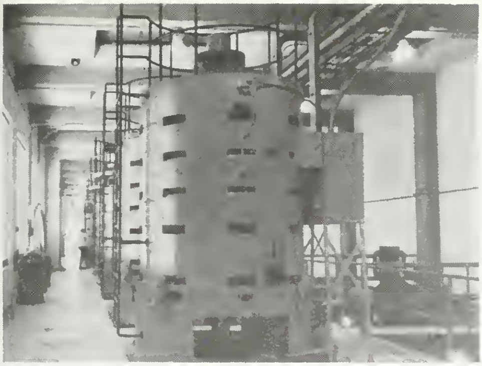

Figure 293. 3,500-Horsepower Synchronous Motors

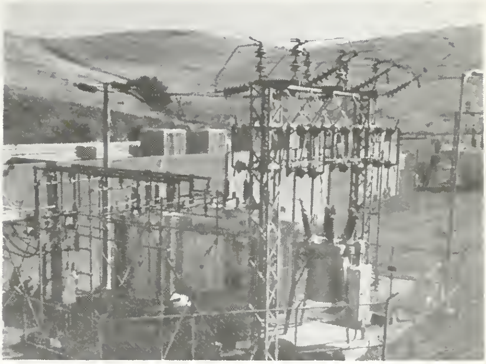

Figure 294. Second-Stage PG&E Substation

Equipment Ratings

Motors

Type: Vertical-shaft, synchronous
Power factor: 100%
Frequency: 60 Hz
Phase: 3
Volts: 4,000

Motor No. 1

Manufacturer: Fairbanks-Morse & Company
Horsepower: 1,250
Speed: 1,200 rpm

Motor No. 2

Manufacturer: Fairbanks-Morse & Company
Horsepower: 2,500
Speed: 900 rpm

Motors Nos. 3 and 4

Manufacturer: Electric Machinery Manufacturing Company
Horsepower: 2,500
Speed: 900 rpm

Motors Nos. 5, 6, and 7

Manufacturer: Fairbanks-Morse & Company
Horsepower: 4,000
Speed: 900 rpm

Motors Nos. 8 and 9

Manufacturer: Ideal Electric Manufacturing Company
Horsepower: 3,500
Speed: 900 rpm

Station Service

Transformer No. 1 (first-stage)

Volts: 4,160–208Y/120
Phase: 3
Frequency: 60 Hz
kVA: 75

Transformer No. 2 (second-stage)

Volts: 4,160–208Y/120
Phase: 3
Frequency: 60 Hz
kVA: 225

Two station service transformers reduce voltage for the distribution cabinets from 4,160 volts to 208Y/120 volts, 3 phase. Each transformer provides power to an independent system. Protective relays, instruments, meters, and local control are installed in the same metal cabinets which house the circuit breakers. Local manual control and controls for remote operation and monitoring of certain features also have been installed (Figure 295). Volume V of this bulletin describes the control system.

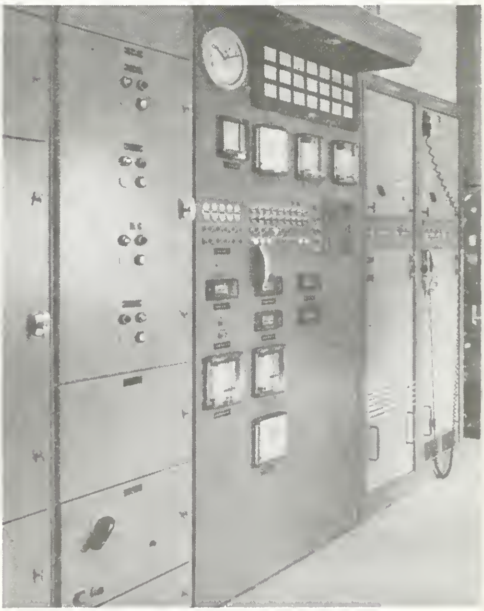

Figure 295. South Bay Aqueduct Control Panel

System Reliability

The required degree of service reliability for both the 4-kV and station service systems was examined during design. Although water delivery was critical in the service areas, an on-line storage reservoir (Del Valle) is available to supplement the flows from South Bay Pumping Plant. This storage availability determination allowed the plant to be partially or totally shut down for maintenance and equipment replacement. Consequently, a single system was provided for each motor and component of the station service system. Back-up feeders or breakers were not installed.

Motor Protection

Motors were considered to be a borderline rating for the extent of protection which was required. Since they were lower in cost and more readily repaired than motors in the major plants of the Project, full protection was not considered necessary. Carbon dioxide protection and a self-contained cooling system were not provided. A more complete protective relay system was installed for the larger motors than for the 1,250-horsepower motor. Cost of the motor and relative cost of the relays was the primary reason for this decision. The selected system also followed the general recommendations of the manufacturers.

Excitation System

Static exciters for the motors were selected for this plant after investigation of the alternates of direct-connected exciters and a single motor-generator set. A common system, using a separate motor-generator set to supply excitation to all units, was attractive from cost consideration but not reliability. Since the plant operates unattended, the need for reliability was of utmost importance. Selection of static exciters rather than direct-connected exciters was made primarily because the static exciters were expected to require less maintenance.

Contracting Procedures

A single procurement contract for the motors combined with the pumps was awarded for the initial units. Pump manufacturers bid on the combined package. The combined procurement was utilized to make one supplier responsible for satisfactory performance of the units; however, the first units installed had inadequate pull-in torque and failed to synchronize. The motors were removed and amortisseur bars of lower resistance were installed; after testing, the modified motors were accepted.

The motors and pumps for subsequent units were separately procured. The Department accepted full responsibility for coordinating the pump supplier and motor manufacturer's designs. Better control of the motor manufacturer by the Department was obtained by separate procurement contracts, and this procedure was later followed on other comparable pump and motor contracts.

Motor Troubles

A motor winding has failed three times in approximately ten years of operation. A single-phase failure to ground occurred on the steel ring used to brace the end turns of the stator windings. Each time, the fault was cleared by the protective relays with sufficient speed to prevent serious damage. A complete rewind of the stator was required to assure reliability rather than partial repair as was done previously. Specifications for rewinding required greater clearance between the tie ring and the windings as well as careful attention to the insulation, tie, and blocking materials.

Loosening of the pole linkage bars for the amortisseur windings has been detected and repaired on three other motors. They would have failed within a short time if not corrected. Repair was done by brazing the connections.

Electrical troubles of the nature experienced with these motors can be anticipated when repeated starts are made with full voltage and high torques. Since this method of starting has the advantage of less equipment and greater starting reliability, it was selected rather than a system which would give longer motor life.

Construction

Contract Administration

General information about the major contracts for the construction of the South Bay Pumping Plant is shown in Table 5. The plant structure was constructed in two stages, and the major equipment was furnished and, in some cases, installed under separate contracts.

First-Stage Construction

Site Excavation. The initial site excavation for South Bay Pumping Plant was an open cut of approximately 9,800 cubic yards made by scrapers assisted by push dozers equipped with rippers. During excavation, a slide occurred necessitating the widening of the cut to arrest further sliding. The site was initially excavated in 1960 (Figure 296).

Dewatering Operations. Although exploratory borings showed ground water to within 4 feet of the ground surface, the site was readily dewatered by pumping from sumps.

Structural Excavation and Backfill. The final excavation also was completed during 1960. In general, the excavation to final grade was made by draglines, clamshells, front-end loaders, and graders, aided by light blasting of calcareous sandstone beds. Excavation for the footing key at the back of the plant was made by line drilling and shooting. Light blasting also was necessary to clear a few large isolated blocks of sandstone in the vicinity of the south wingwall. Extensive use of jackhammers was necessary to achieve final grade in the excavation. Temporary cut slopes

TABLE 5. **Major Contracts—South Bay Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
South Bay Pumping Plant and discharge line	60-01	$815,270	$869,156	$34,996	6/ 1/60	5/23/62	Fred J. Early, Jr., Co., Inc.
Furnish pump units Nos. 3 and 4 for South Bay Pumping Plant	63-13	108,300	114,256	333	4/11/63	4/12/64	FMC, Hydrodynamics Division Peerless Pump
Install units for South Bay Pumping Plant	63-15	79,880	88,222	--	7/25/63	5/15/64	Fred J. Early, Jr., Co., Inc.
Furnish pump units Nos. 8 and 9 for South Bay Pumping Plant	63-33	129,021	141,860	7,640	10/24/63	10/ 8/64	Johnston Pump Company
South Bay Pumping Plant and discharge manifold	63-34	592,777	632,926	36,063	10/22/63	8/31/65	S & Q Construction Co.
Discharge valves and hydraulic system for South Bay Pumping Plant	63-40	52,921	48,626	--	2/25/64	1/ 4/65	Chapman Valve Mfg. Co.
Vertical motors pumping units Nos. 5, 6, and 7 for South Bay Pumping Plant—2nd stage	67-13	254,952	265,175	--	5/ 1/67	6/18/70	Fairbanks-Morse Co.
Completion of South Bay Pumping Plant—2nd stage units—Units Nos. 5, 6, and 7	67-35	568,485	598,944	27,832	10/17/67	6/16/69	Wismer & Becker Contracting Engineers

held up well with the exception of a few minor dip-slope failures in the south wall of the cut.

Approximately 4,300 cubic yards of native material was used for structural backfill which was compacted by gasoline-powered manually held tampers. Oversize stones were removed by hand.

Concrete Placement. Concrete for the first-stage pumping plant was furnished by a commercial transit mix company. Concrete was batched at the plant and mixed in transit mixers en route to the construction site.

The concrete was composed of Type II cement. Two basic mixes were used: one with 5½ sacks of cement per cubic yard and one with 6. In both mixes, pozzolan was substituted for approximately 15% of the cement, and an air-entraining agent was used to entrain approximately 4% air (by volume).

Universal form panels were used to form the plant substructure, retaining walls, and drainage chute. Conventional plywood forms were used for the plant superstructure. The universal form panels were completely disassembled, cleaned, and oiled after each use.

Concrete was cured by water or by membrane curing compound. Water curing was generally by flooding or by soaker hoses. Vertical surfaces usually were wet as soon as the forms could be loosened and were kept damp for 14 days. Surfaces which would be later covered or backfilled were membrane-cured.

Discharge Line. Approximately 12,000 cubic yards of material was excavated for the steel pipe. Most of the material was Panoche sandstone and shale with an average of 3 to 4 feet of soil cover. Excavation was made with a backhoe facilitated by line drilling and blasting. Holes were drilled at 5-foot centers and loaded with 22 pounds of 40% Hercules Powder.

In general, near-vertical trench sides were stable 10 to 15 feet high. Several areas where the excavation was about 18 feet deep proved unstable, and the upper

Figure 296. Completed Rough Plant Excavation—First-Stage Construction

portions of the trench sides were sloped back sufficiently to provide stability (Figure 297).

Final cleanup of the pipe trench was made by a small track-type tractor equipped with a front-end loader which also was used to spread and shape the sand bedding material for the pipe.

After fabrication in nominal 40-foot lengths, the pipe was transported to a yard where it was lined and coated with coal-tar enamel. Then it was trucked to the site and placed directly in the trench. The work was scheduled to permit direct installation to minimize damage to the coating through handling.

Pipe joints were butt-welded and radiographed and, after all defects were corrected, the interior surfaces of the joints were coated with coal-tar enamel. Outside surfaces were wrapped with 20-mil plastic tape with a 50% lap. After final inspection of the pipe coating by a holiday detector, sand backfill was placed over the pipe and consolidated by jetting and vibrating. Following that, the trench was backfilled with excavated material and the site was cleaned up.

Surge Tank. The surge tank was founded on firm Panoche sandstone. The 18-foot-deep excavation slopes varied from 1½:1 to 1:1. The tank was shop-fabricated in two main sections, both 13-foot inside diameter. The sections, one 15 feet and 5 inches long and one 78 feet and 9 inches long, were shipped by rail and trucked to the job site and installed.

During erection, chokers instead of the lifing lugs were used making it difficult to maneuver the tank section into position, necessitating the use of two cranes with booms shorter than the top of the tank.

It was difficult to obtain an acceptable field weld due to strong wind. Most of the original field welds were removed by backgouging and rewelded from inside the tank. Before final acceptance of the weld, it was radiographed to spot defects which were removed and rewelded.

A bulkhead was erected at the surge tank outlet in December 1961. A steel bulkhead was placed at the surge tank outlet, flush with the inside of the tank, and sealed with a gasket material made of rubber-insulated electrical wire. The tank was filled for the first time in late December 1961 and was watertight.

Second-Stage Construction

Modification to First-Stage Work. To prevent a large inflow of water into the excavation for the second-stage South Bay Pumping Plant and to permit excavation in the dry, it was necessary to construct a cofferdam in the north area of the first-stage South Bay Pumping Plant north wingwall.

Bracing for the north wingwall also was provided because it was not designed to withstand the unbalanced pressure resulting from the excavation on the north side of the wingwall. The bracing consisted of a concrete thrust block with two levels of H-beam braces.

Figure 297. Placing 54-Inch Steel Discharge Pipe in Trench

The cofferdam was formed by driving 36 sheet piles in front of the two levels of H-beam bracing. Initially, the sheet piling was driven with an 85-pound jackhammer but, due to slow progress, was completed with an 800-pound air-driven hammer. Additional soil was placed on the water side of the sheet piling to decrease the seepage into the excavation.

Sheet piling also was driven at the northeast corner of the existing first-stage pumping plant to stabilize the consolidated backfill for the first-stage pipe and the drain rock. This sheet piling also served to restrict the flow of water into the excavation from the drain material around the first-stage pumping plant.

The contractor was required to remove the north 6- to 9-inch-thick concrete wall of the superstructure of the first-stage pumping plant and install a temporary wall. This north wall had been joined to the permanent structure by a cold joint and was doweled to facilitate removal. A temporary stud and plywood wall was installed (Figure 298).

Site Excavation. Site and forebay excavation included the removal and disposal of all materials above the design finish grade elevations, all excavation on the upstream side of the trashrack piers including sloping of the forebay cut, and all excavation necessary for a paved drainage ditch. Site excavation began in November 1963 using two scrapers, two dozers, and a motor grader.

Excavated material suitable for compacted backfill was stockpiled on the west side of the Pumping Plant, and the rest of the excavated material was wasted in the designated area across the forebay to the east of the plant. Most of the site excavation was completed prior to the start of structure excavation, and the remainder was done after completion of the structure.

Some of the forebay excavation for the area upstream of the trashrack piers was made in conjunction

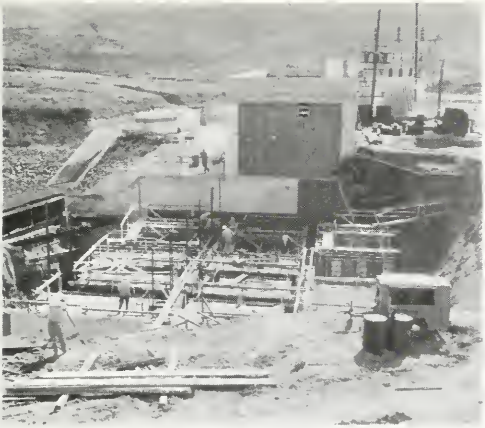

Figure 298. Temporary Stud and Plywood Wall

with the structure excavation. However, most of the forebay excavation commenced on November 16, 1964, after much of the plant structure was completed. The forebay level was scheduled to be raised to elevation 241 feet by December 1, 1964 to ensure sufficient water storage in Bethany Reservoir for water deliveries during the planned shutdown of the Delta-Mendota Canal from December 1, 1964 to February 1, 1965. The Canal was, at that time, the source of water for Bethany Reservoir. Therefore, it was desirable to complete the forebay excavation before the water level was raised to elevation 241 feet.

All material in the dry between the cofferdam, wingwalls, and structure was removed by a backhoe, dozer, and two scrapers. The backhoe could not handle the hard sandstone and progress was slow. The cofferdam was removed on November 19, 1964. In late November, it was necessary to start raising the reservoir level, and it was then apparent that the forebay excavation would not be completed before the reservoir level rose to elevation 241 feet, and operations were suspended. In February 1965, after the reservoir level was lowered, the forebay excavation was resumed by drilling and blasting the rock and hauling the excavated materials in scrapers loaded by a small dragline. In March 1965, all site and forebay excavation essentially was complete. Approximately 8,700 cubic yards were excavated.

Structural Excavation. Excavation for structures included the removal and disposal of all material to finish grade for the construction of the Pumping Plant, appurtenances, piping, manifold, concrete anchors, and sewer lines. The plant structure excavation was made with two scrapers, a dozer, and a backhoe. Drilling and blasting of hard rock were necessary. Foundation trenches were excavated by hand.

Keeping structure excavation dry was difficult due to inflow of water through the cofferdam and from around the drain rock placed on the side of the first-stage pumping plant. A diver was used to plug the 4-inch-diameter weep holes in the first-stage pumping plant wingwalls and intake wells to reduce the water coming from around the first-stage plant. Sump pumps also were used to keep the excavation dewatered.

Part of the excavation for the discharge lines and manifold was completed using the above equipment, but both a grader and an excavator were used for the manifold excavation which was slow due to equipment breakdown resulting from the hard rock. All manifold excavation was completed in October 1964.

Backfill. Compacted backfill was placed around the structure using mechanical hand tampers and air hammers for tight areas and, where space permitted, a sheepsfoot roller. Material for structure backfill was selected and stockpiled in the area west of the plant and moisture-conditioned in the stockpile before transporting to the placement. Ninety-five percent relative compaction was required for all compacted backfill.

A curtain of free-draining material ($\frac{3}{16}$ to $1\frac{1}{2}$ inches) 2 feet wide was placed and consolidated along the exterior of the plant structure and below the valve gallery floor slab. This curtain extends from elevation 226 feet to elevation 245 feet on the north side of the plant and to elevation 251 feet on the west side of the plant. The 4-inch weep holes in the north wingwall and intake wall join this drain curtain. The drain rock was flooded and then consolidated 3 to 6 inches by immersion-type vibrators. This material was placed concurrently with the adjacent backfill using a 2-foot-high wood form braced to the wall to separate the materials and, after removing the form, revibrating the drain rock.

The consolidated backfill was placed in the manifold and discharge pipe area from 3 inches below the discharge pipe to within 2 feet of final grade. Concrete sand was used for the backfill and was consolidated to 95% of the maximum density by flooding and using 3-inch and 6-inch immersion-type vibrators.

Concrete Placement. The concrete for this contract was batched, mixed, and transported by a commercial transit mix company located in Tracy, California. Sand and aggregate were obtained from a pit adjacent to Tracy. Type II cement, pozzolan, an air-entraining agent, and a water-reducing agent were used in all concrete mixes. Three different concrete mixes plus a starter mix were used and transported to the job site in 6-cubic-yard transit mix trucks.

In August 1964, concrete placements for the exposed pumping plant walls began before 6 a.m. and were completed by 10 a.m., or sufficient ice was substituted for mixing water to maintain the concrete temperature below 80 degrees Fahrenheit when discharged from the transit mixer. The coefficient of variation of 7.7% for the 28-day concrete strengths was excellent.

Both standard-type forms (plywood, studs, and walers) and universal form panels were used. The substructure was divided into three approximately 10-foot lifts above the foundation slab, and each lift was divided into two separate placements (Figure 299). The contractor ganged the universal forms into 10-foot-high panels for the required widths in the substructure walls. The superstructure wall panels were ganged into 16-foot-high panels.

There were 21 major structure concrete placements for the substructure, superstructure, and wingwall along with minor concrete placements. Except for the usual problems involved in getting the forms ready for concrete placements, most placements were routine. The ganged universal form sections were difficult to align. All concrete surfaces were water-cured except those surfaces later covered with concrete or earth which were membrane-cured.

Discharge Lines and Manifold. The discharge manifold was transported to the job site in four sections for field assembly and welding. The 30-inch-diameter piping was furnished with extra length to permit cutting and final field fitting. All field welds were 100% radiographed and defective weld areas removed by an air arc. After rewelding, the areas were radiographed again and rewelded, if required.

The fabrication of one manifold section was not correct. The outlet for an 8-inch-diameter blowoff line was misplaced 4 feet downstream, and 4 feet of an 8-inch-diameter steel pipe and an elbow were added to correct this, requiring the placement of additional thrust block concrete.

Installation of the manifold and discharge lines commenced on October 1, 1964 and were ready for hydrostatic testing on October 29, 1964. Instead of hydrostatic testing the manifold and discharge pipes, by installing a bumped head on each of the 30-inch-diameter discharge pipes and at the 66-inch-diameter end of the manifold as specified, the contractor obtained approval to connect the discharge piping to the embedded pipe sections with dresser couplings and test against the concave side of the bumped head on the manifold and against the blind flanges installed on 30-inch-diameter discharge pipes in the valve gallery. The contractor's approved detail proposed four clips and a saddle welded on the discharge pipe on each side of the dresser coupling with four $1\frac{1}{2}$-inch-diameter bolts securing the pipe against the longitudinal force. The underside clips and bolt were unusable due to interference by the concrete supports for the discharge pipe so additional $\frac{3}{8}$-inch-thick steel straps were welded across the three remaining clips of the dresser coupling.

The manifold and discharge pipe were filled with water and tested on November 2, 1964, at 100 to 300 pounds per square inch gauge (psig). Several small leaks developed at the dresser couplings which were corrected by adjusting the dresser couplings. At 375 psig, the anchor clips started bending so the test was discontinued. After reinforcing the anchor clips by additional welding and steel straps, the hydrostatic test was resumed on November 3, 1964. The pressure was brought up to 400 psig without incident. All welds and joints were checked with the pressure held at 400 psig and found to be satisfactory with no leakage. After satisfactory completion of the hydrostatic test, the manifold was encased in concrete and backfilled.

As described above, the test at 400 psig was made against the concave side of the bumped head on the 66-inch-diameter end of the manifold. After completion of the manifold installation, the contractor for the second-stage discharge line proposed to hydrostatic test that line against this bumped head from the convex side. When the line was nearly filled, the bumped head failed, filling the manifold with water. Flooding of the plant was prevented by the blind flanges and the plant discharge valves. The water discharged through an open 20-inch-diameter manhole in the manifold, damaging the pumping plant exterior and silting the forebay. Subsequent tests were satisfactory.

Other Construction

Construction of the pumping plant superstructure and other building components was routine.

Pumping units were furnished and installed by several different contractors in separate phases. No unusual methods were employed.

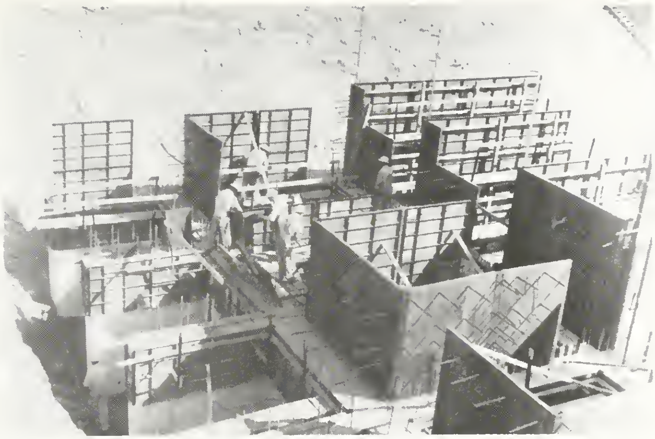

Figure 299. Forms for Second Lift

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 300 through 318).

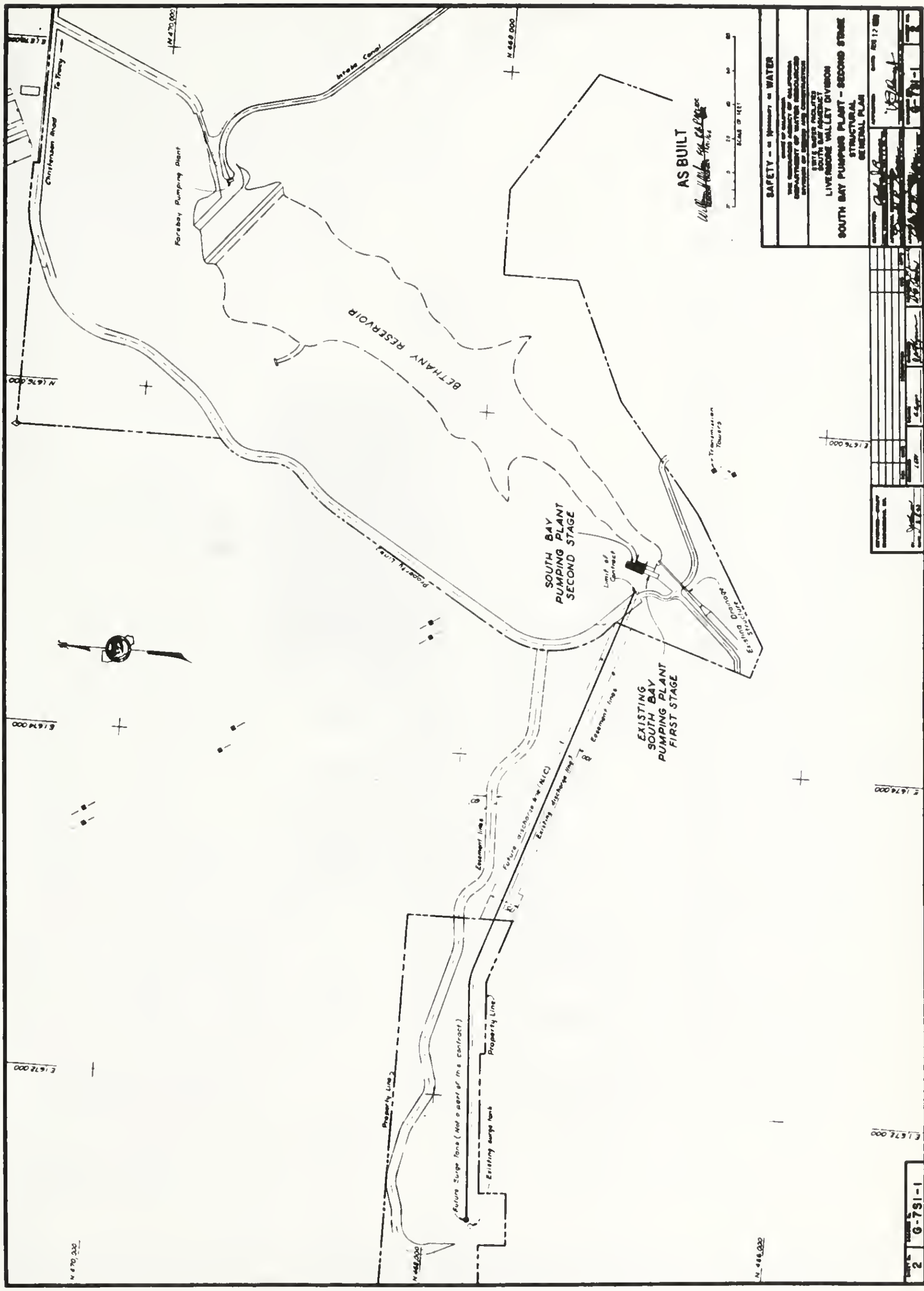

Figure 300. General Plan

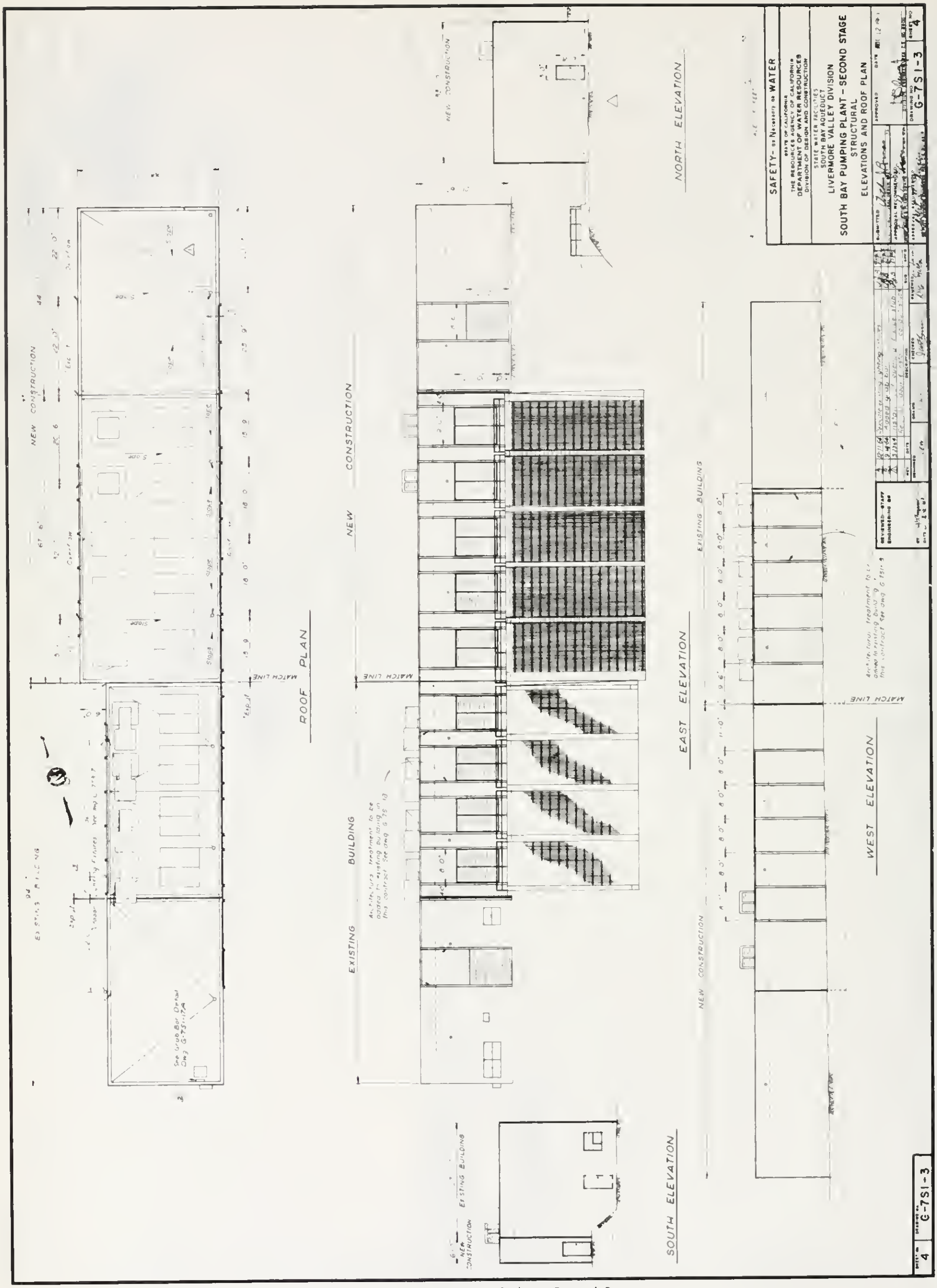

Figure 301. Elevations and Roof Plan—Second Stage

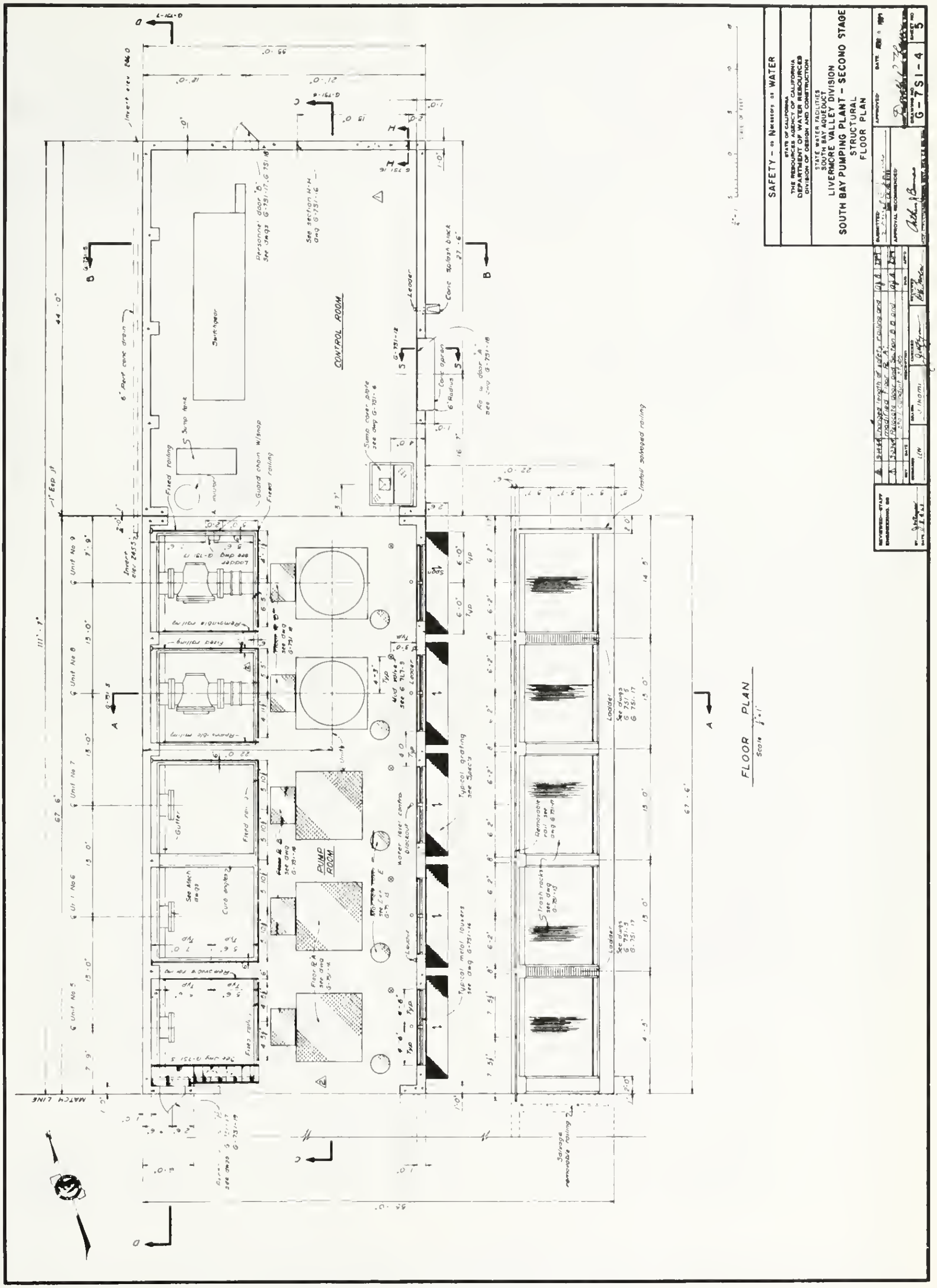

Figure 302. Floor Plan—Second Stage

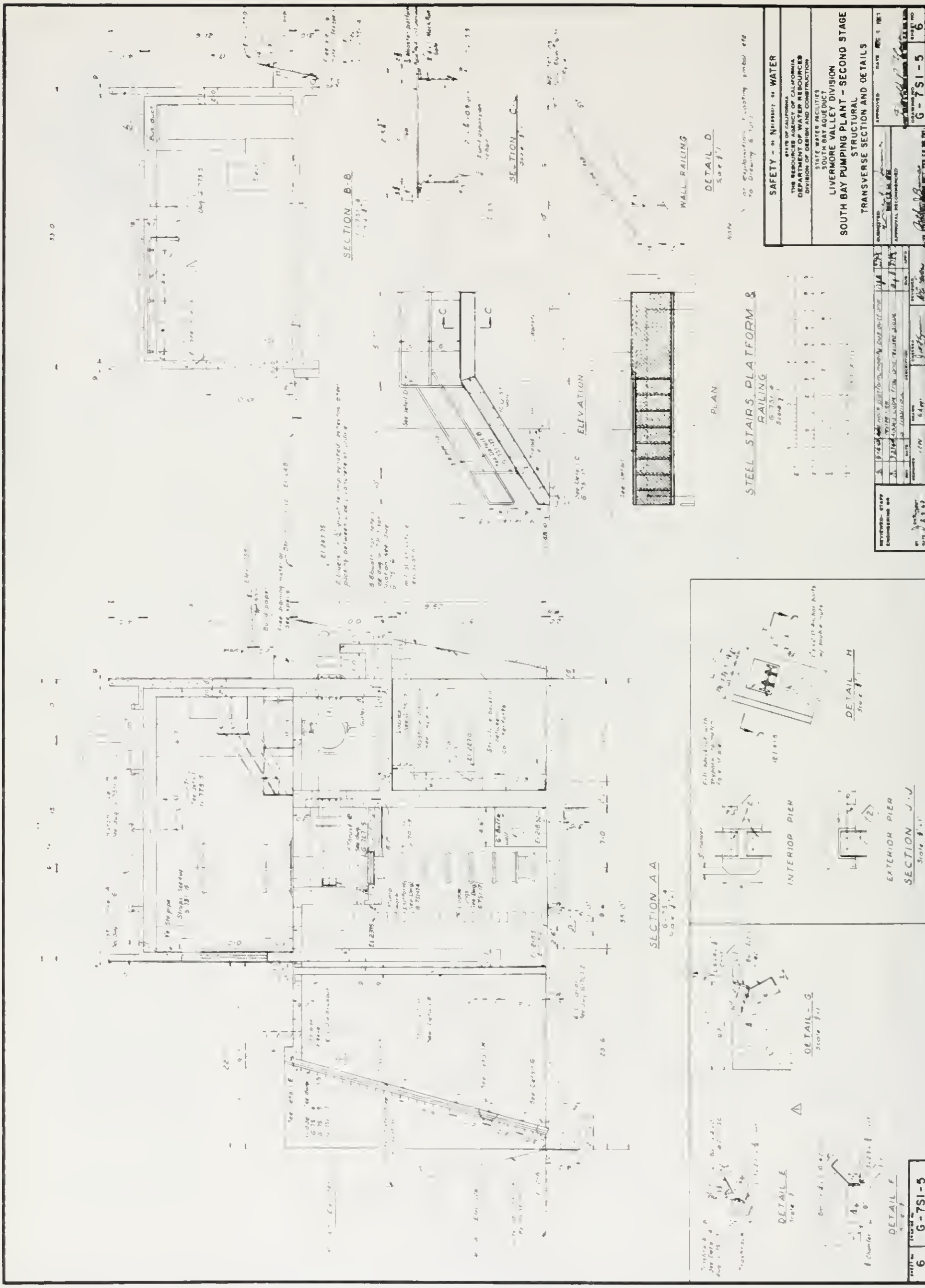

Figure 303. Transverse Section and Details—Second Stage

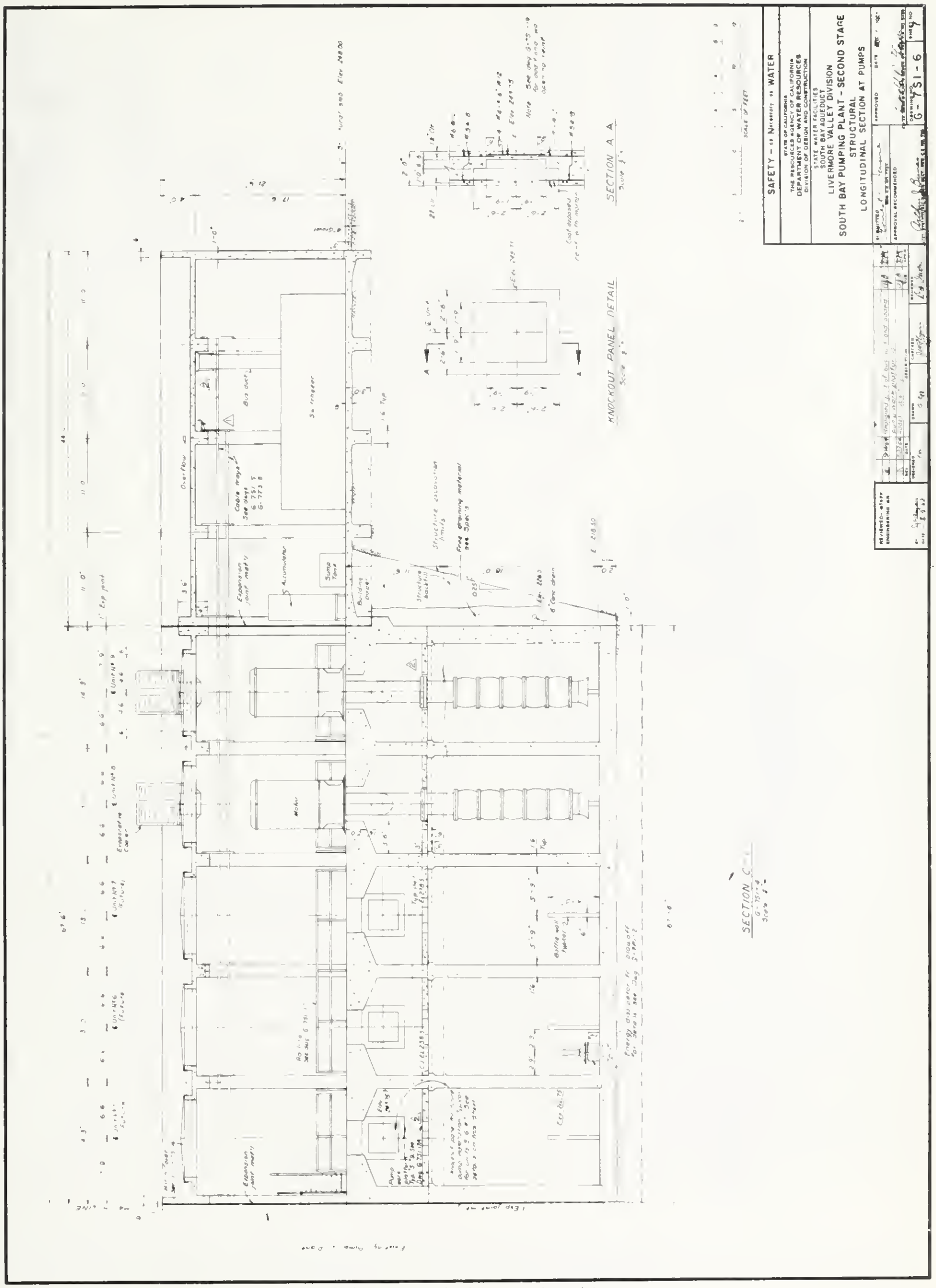

Figure 304. Longitudinal Section—Second Stage

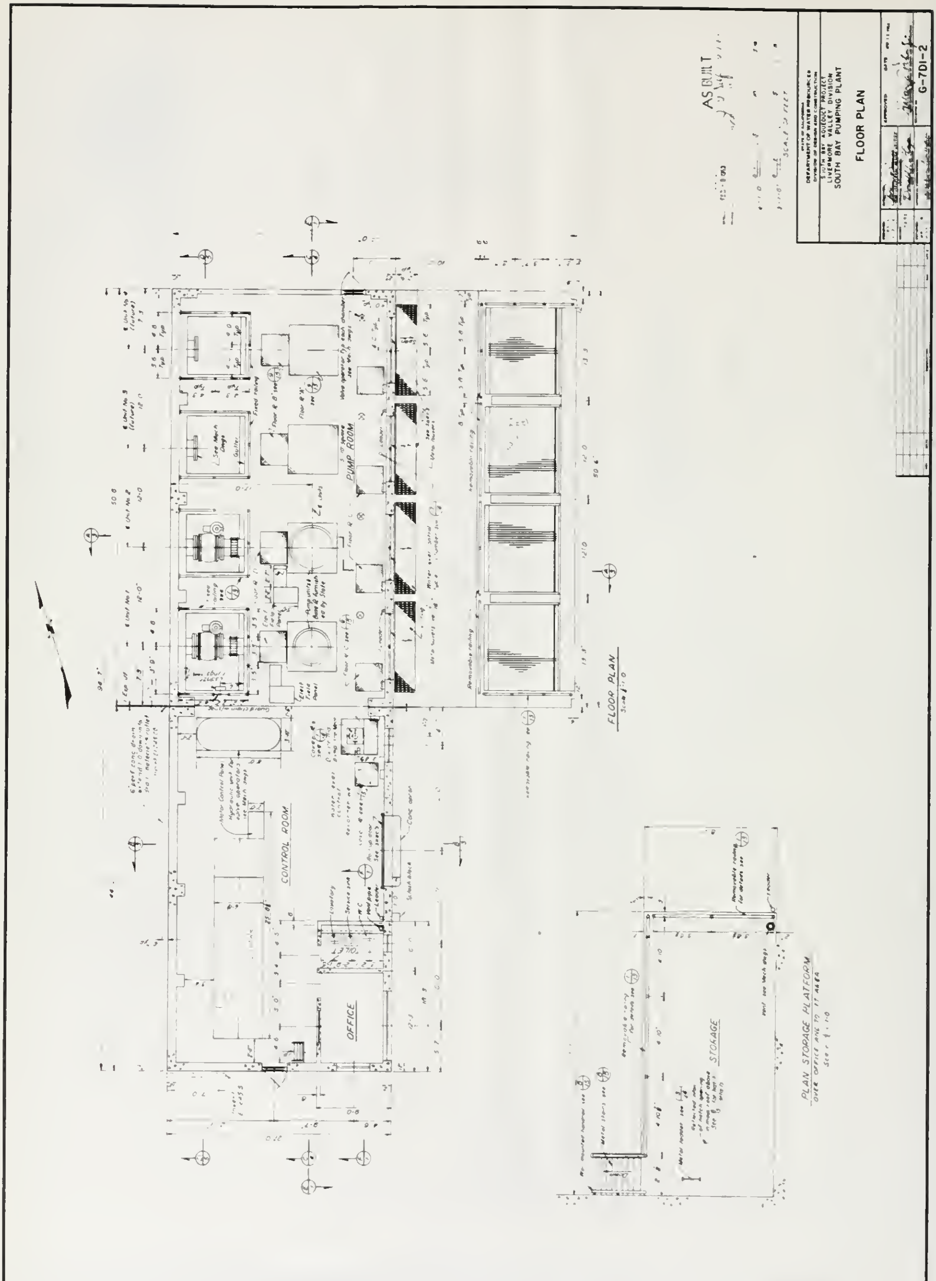

Figure 305. Floor Plan—First Stage

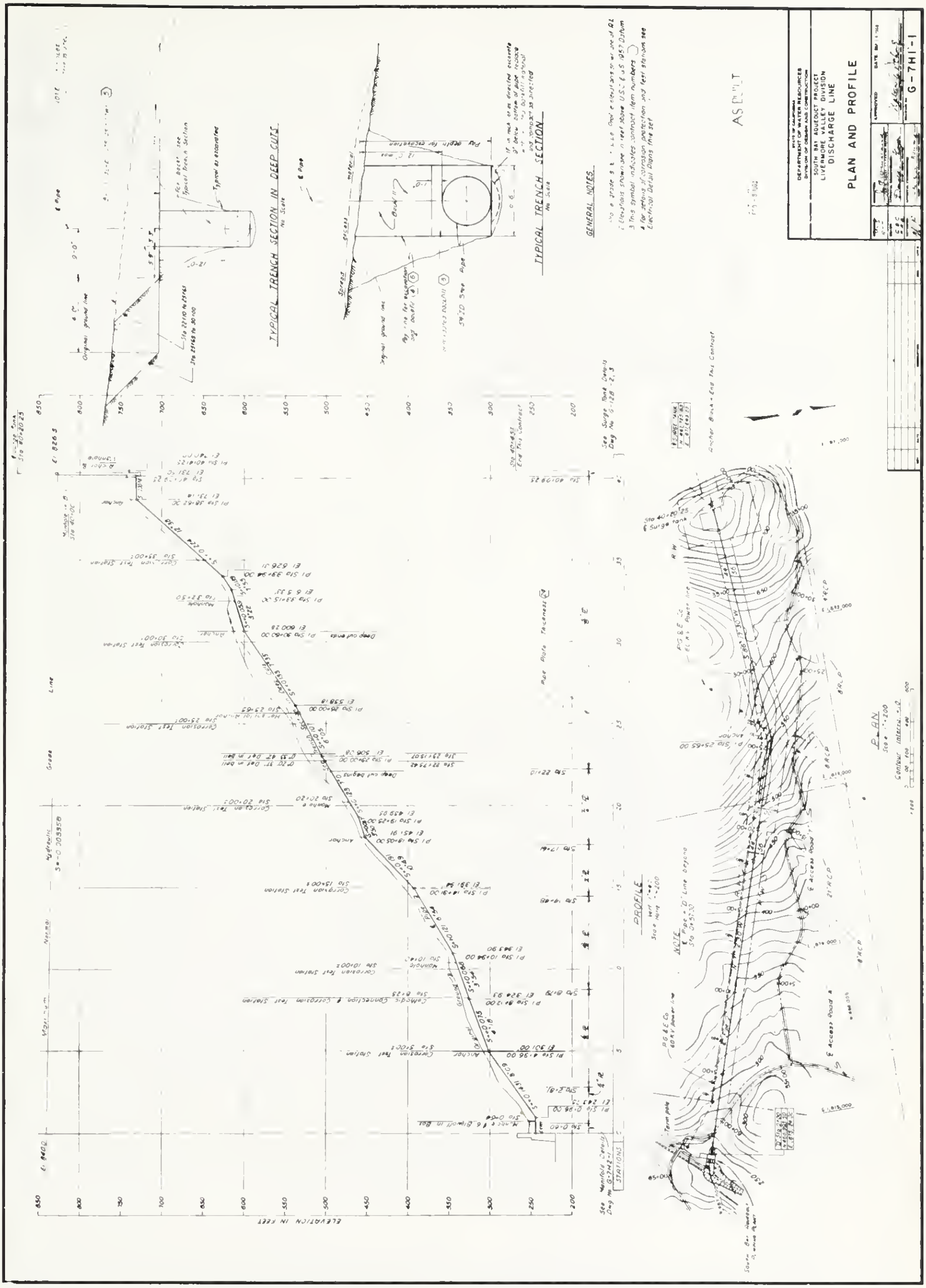

Figure 306. Discharge Line—Plan and Profile

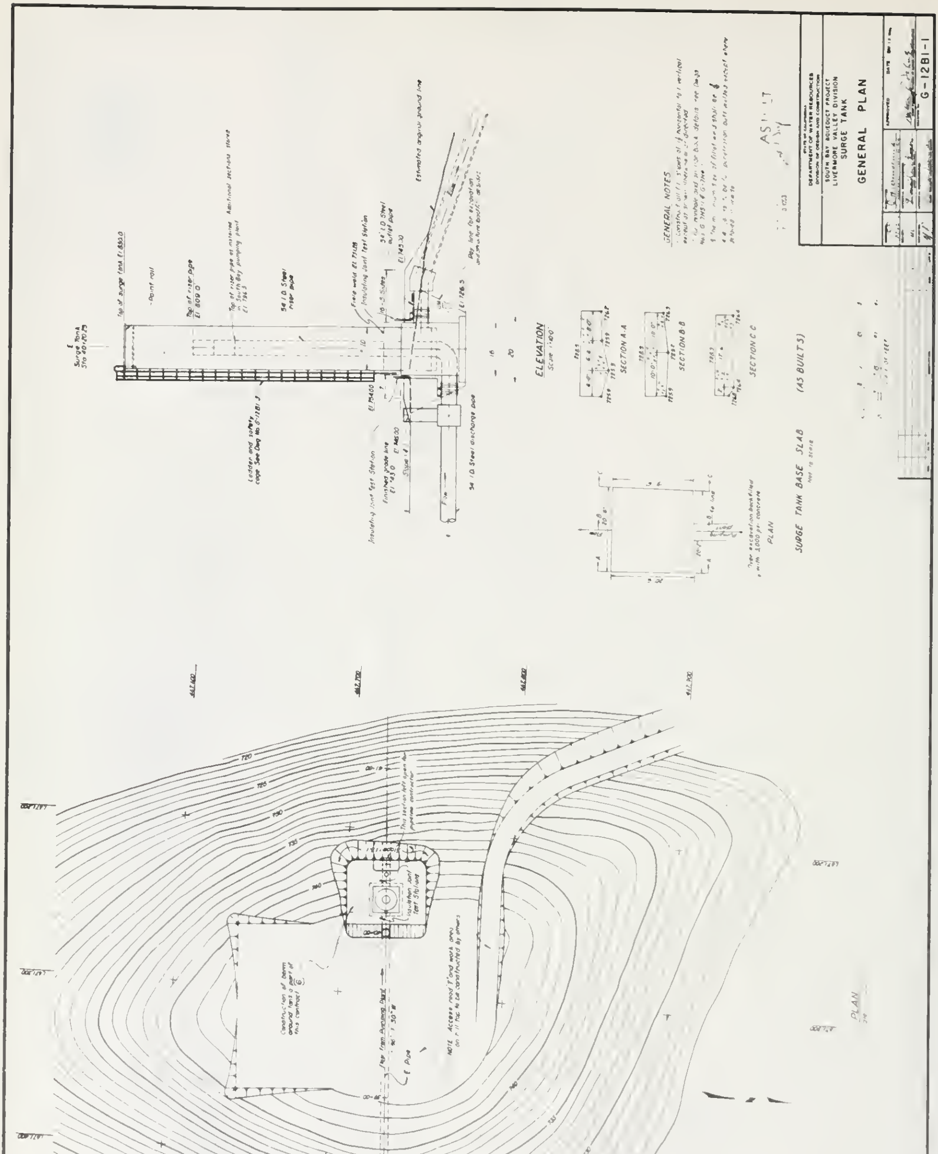

Figure 307. Surge Tank—General Plan

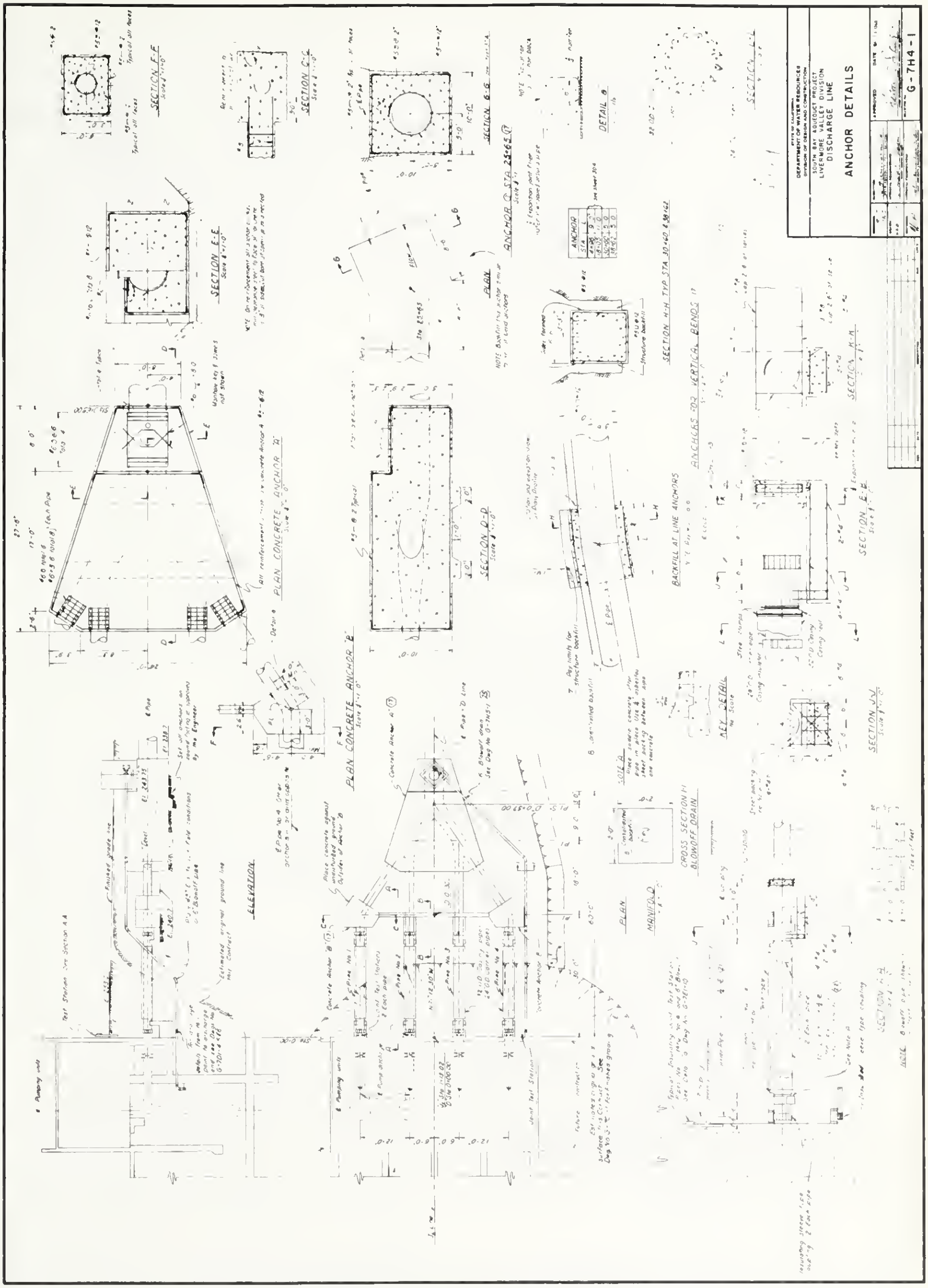

Figure 308. Discharge Line—Anchor Details

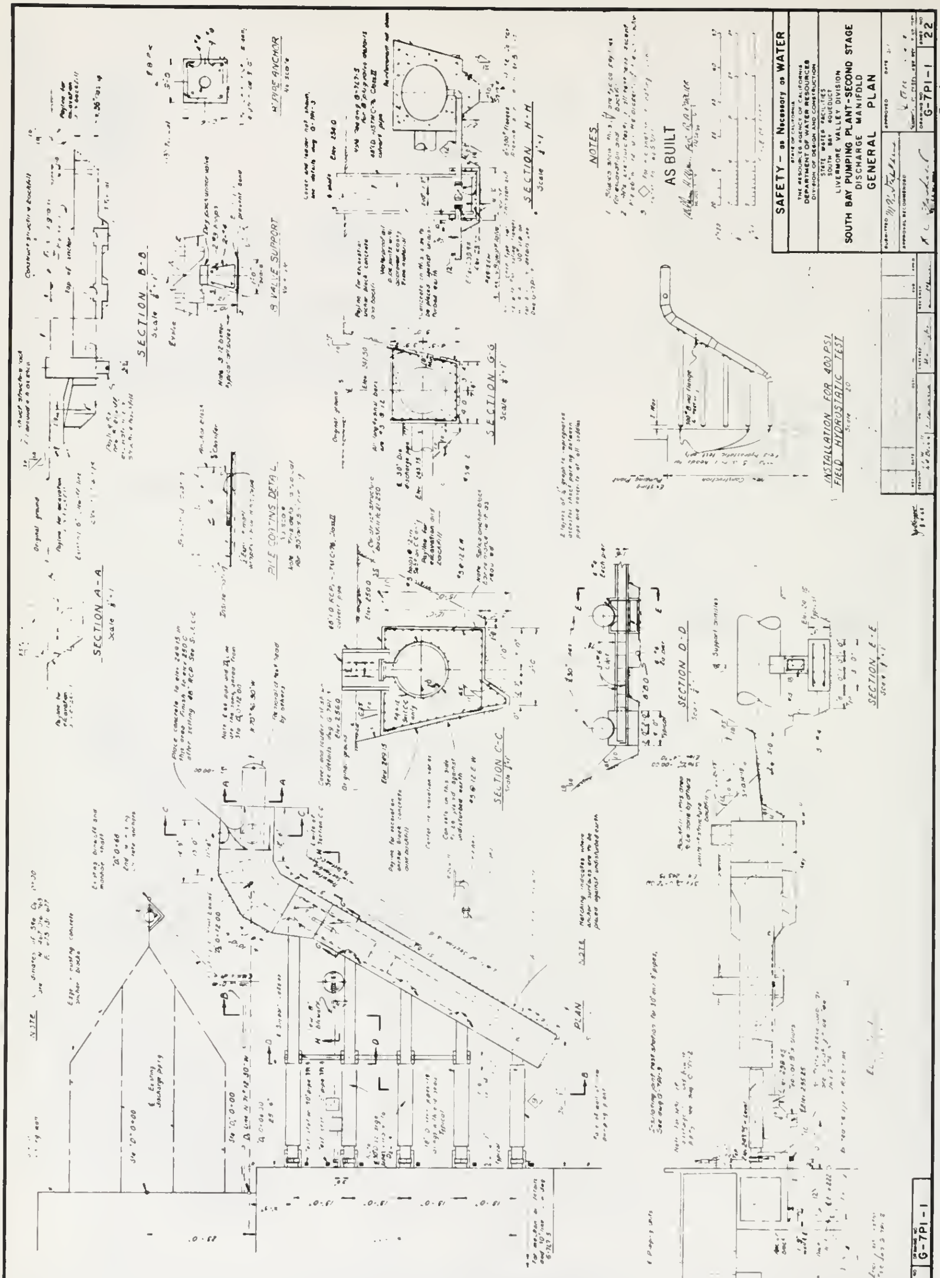

Figure 309. Discharge Manifold—Second Stage

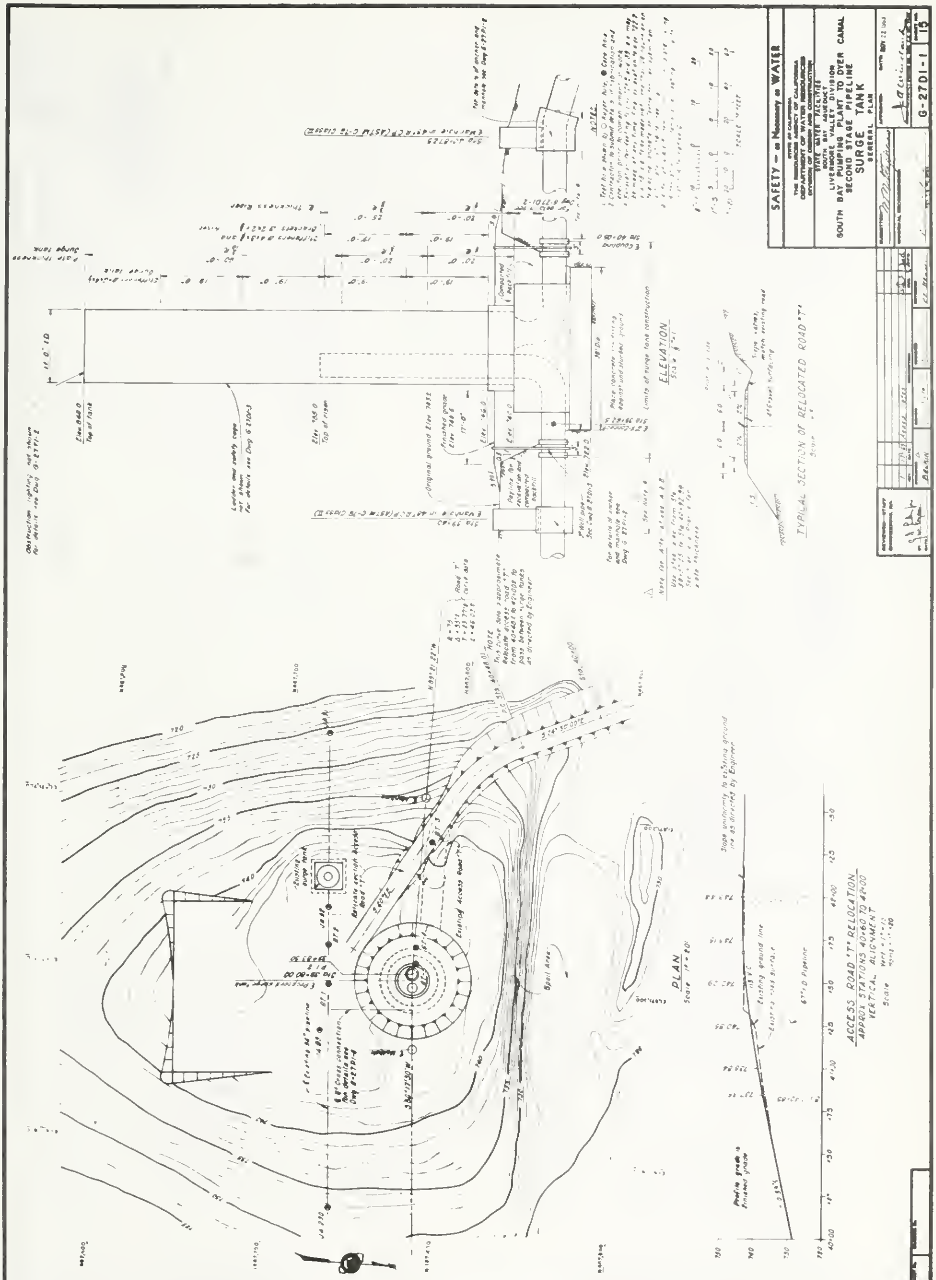

Figure 310. Surge Tank—Second Stage

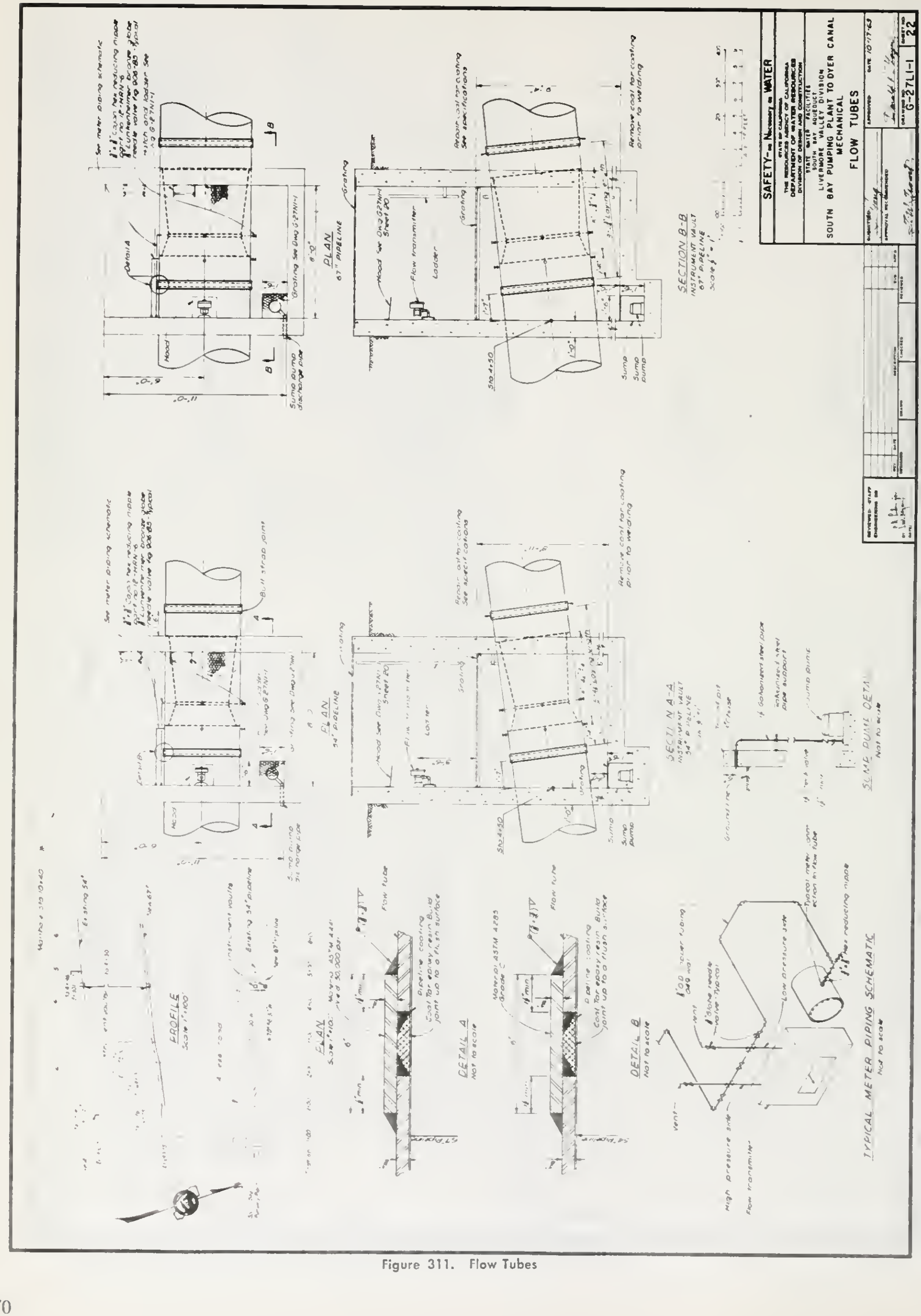

Figure 311. Flow Tubes

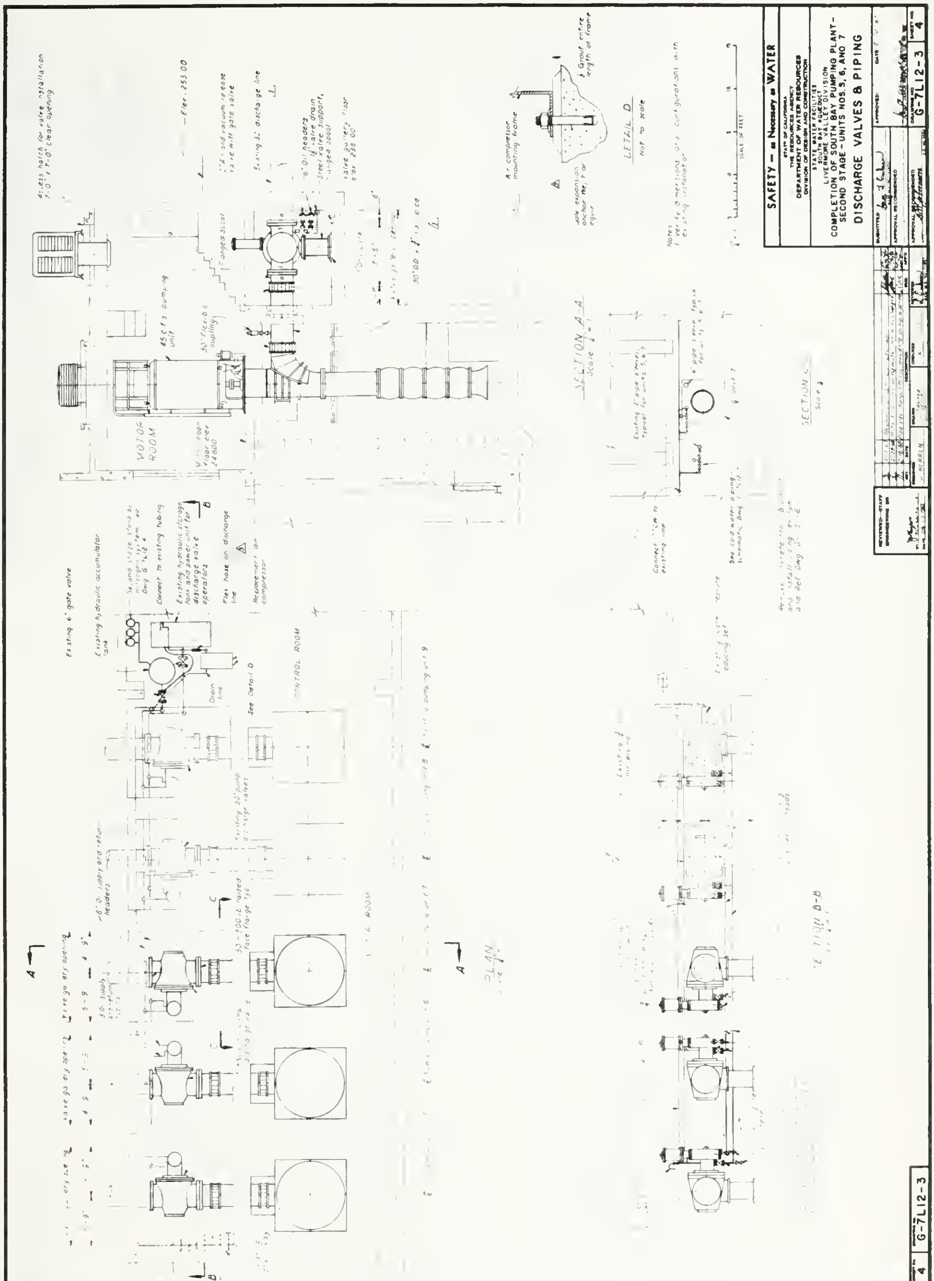

Figure 312. Discharge Valves and Piping—Second Stage

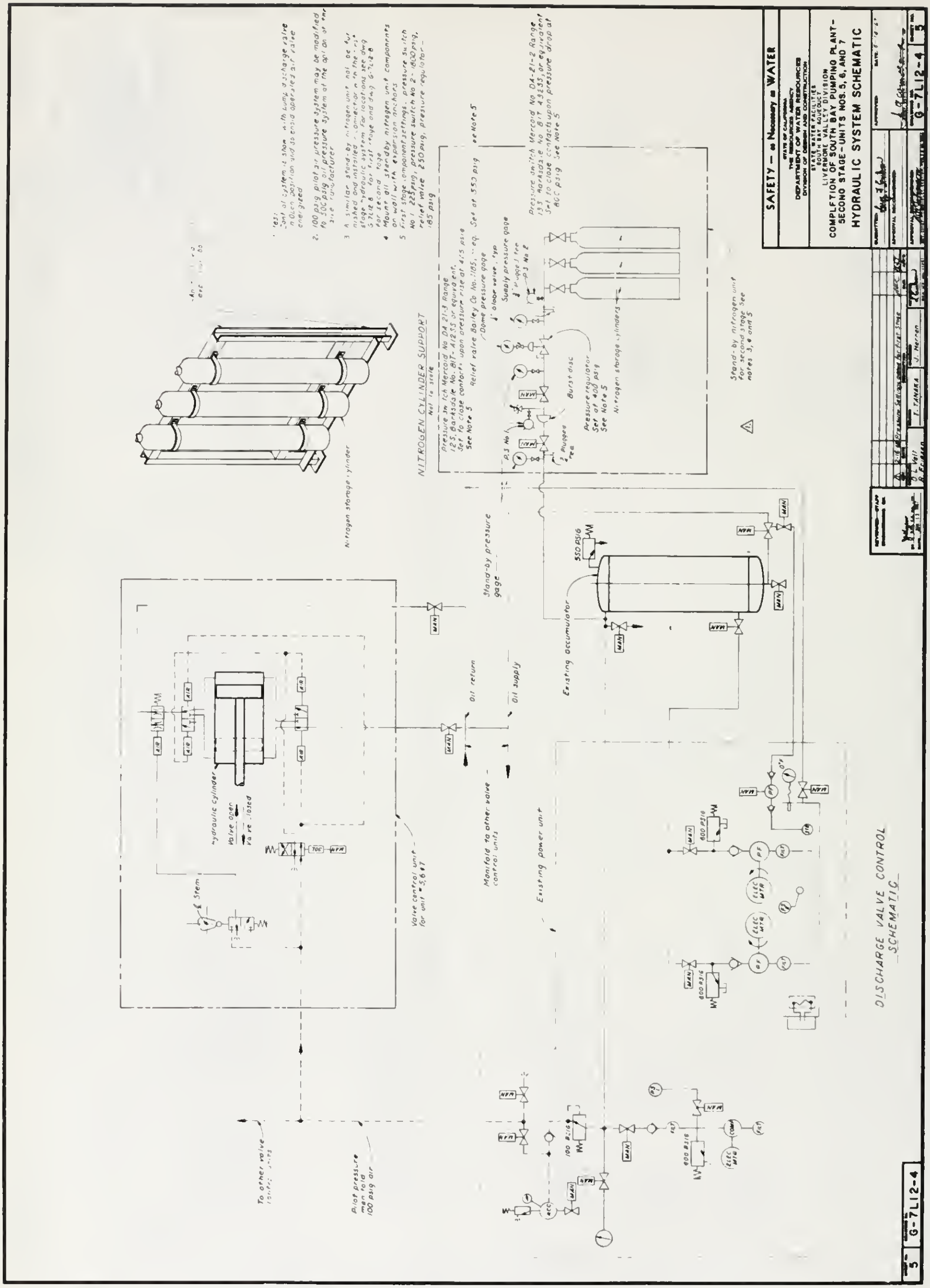

Figure 313. Hydraulic System Schematic—Second Stage

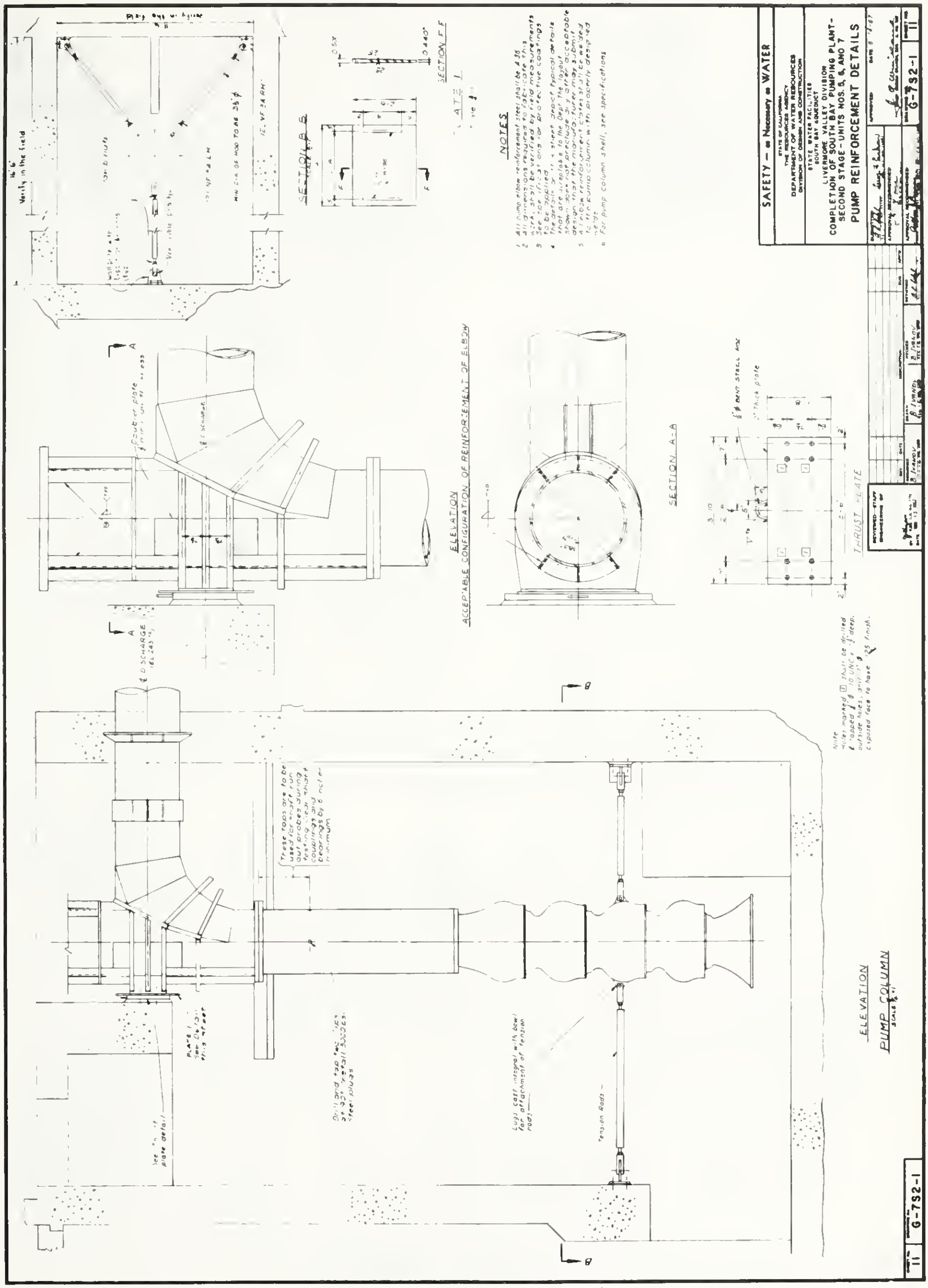

Figure 314. Pump Reinforcement Details—Second Stage

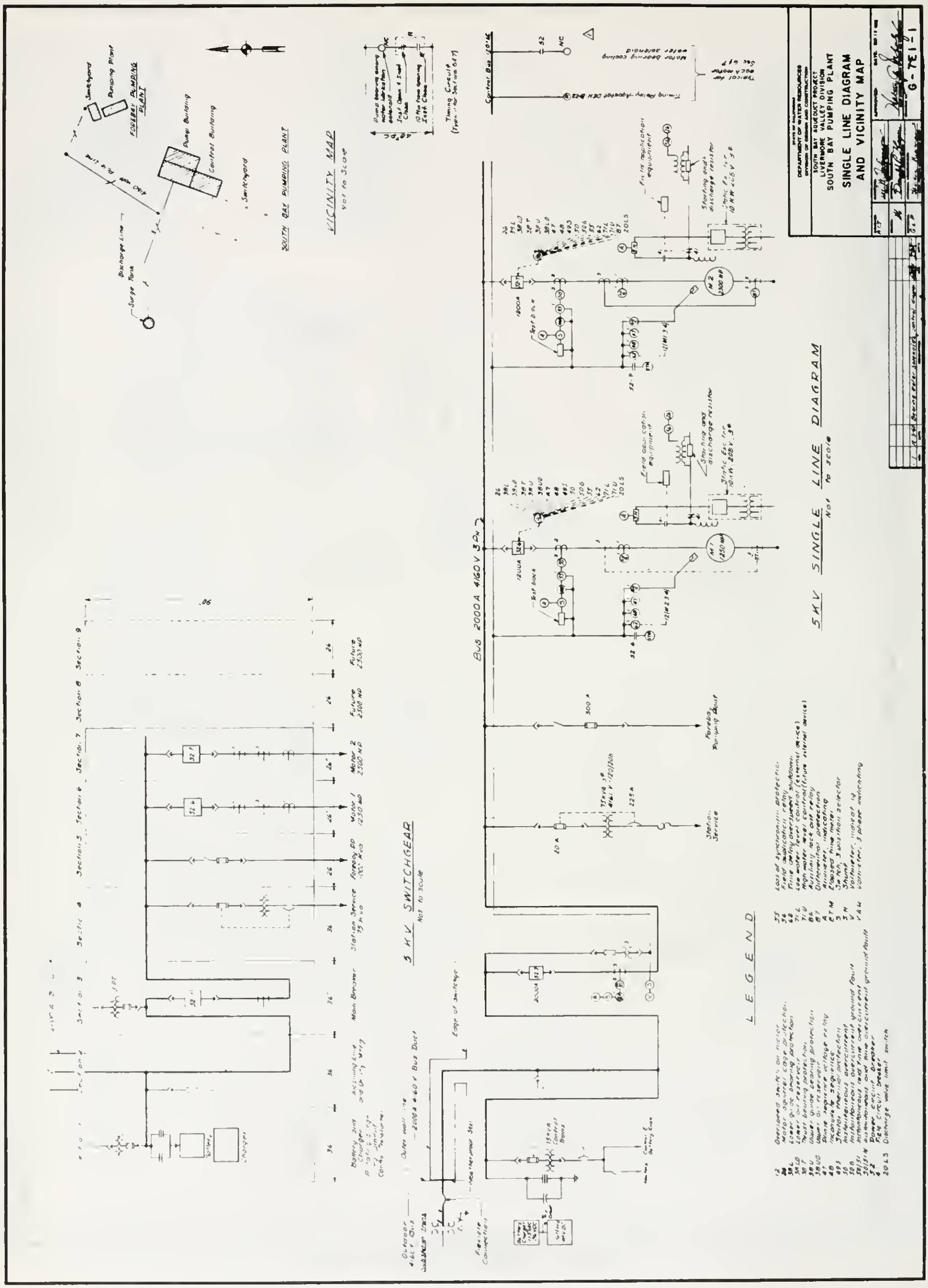

Figure 315. Single-Line Diagram—First Stage

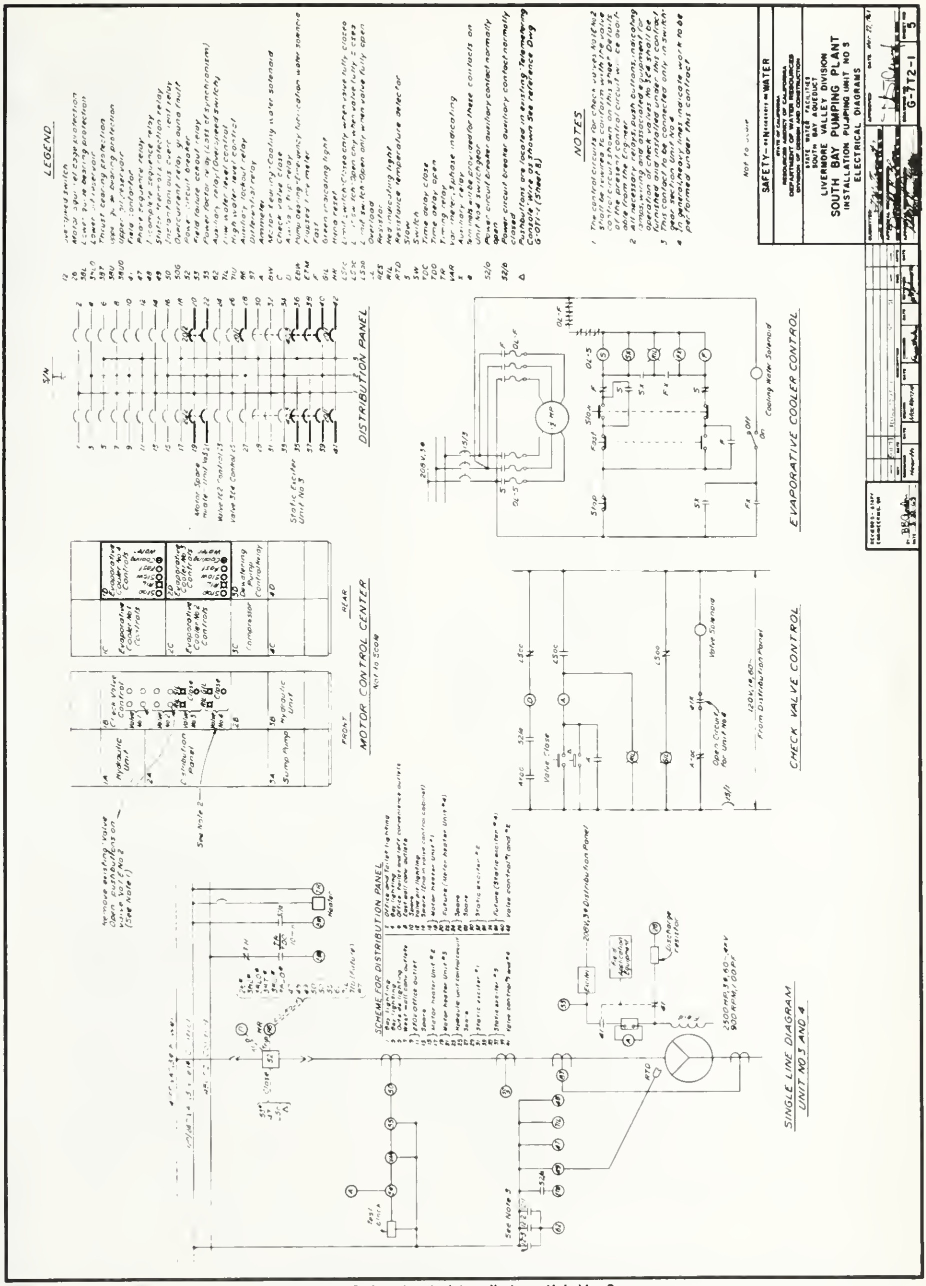

Figure 316. Electrical Installation—Unit No. 3

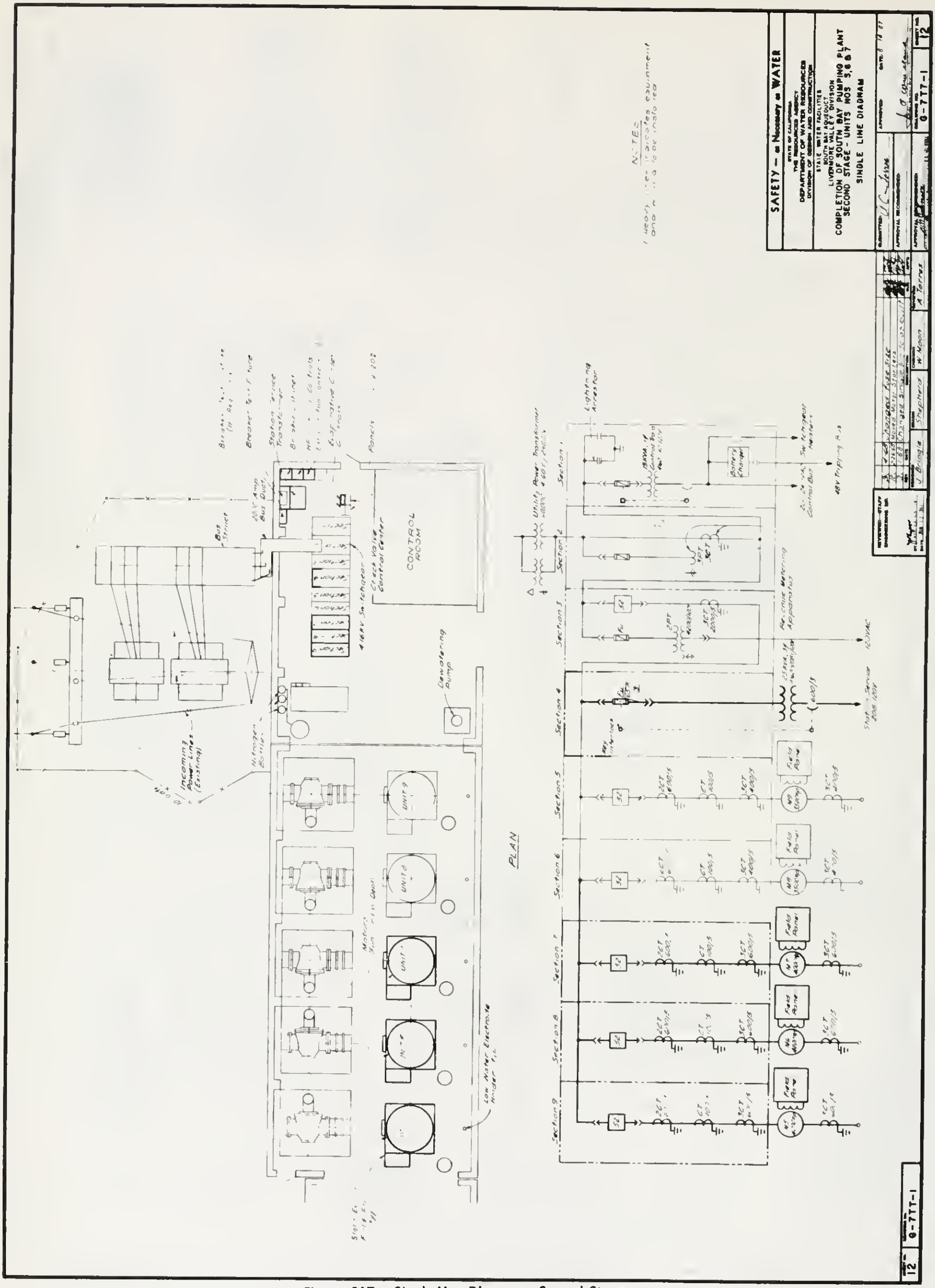

Figure 317. Single-Line Diagram—Second Stage

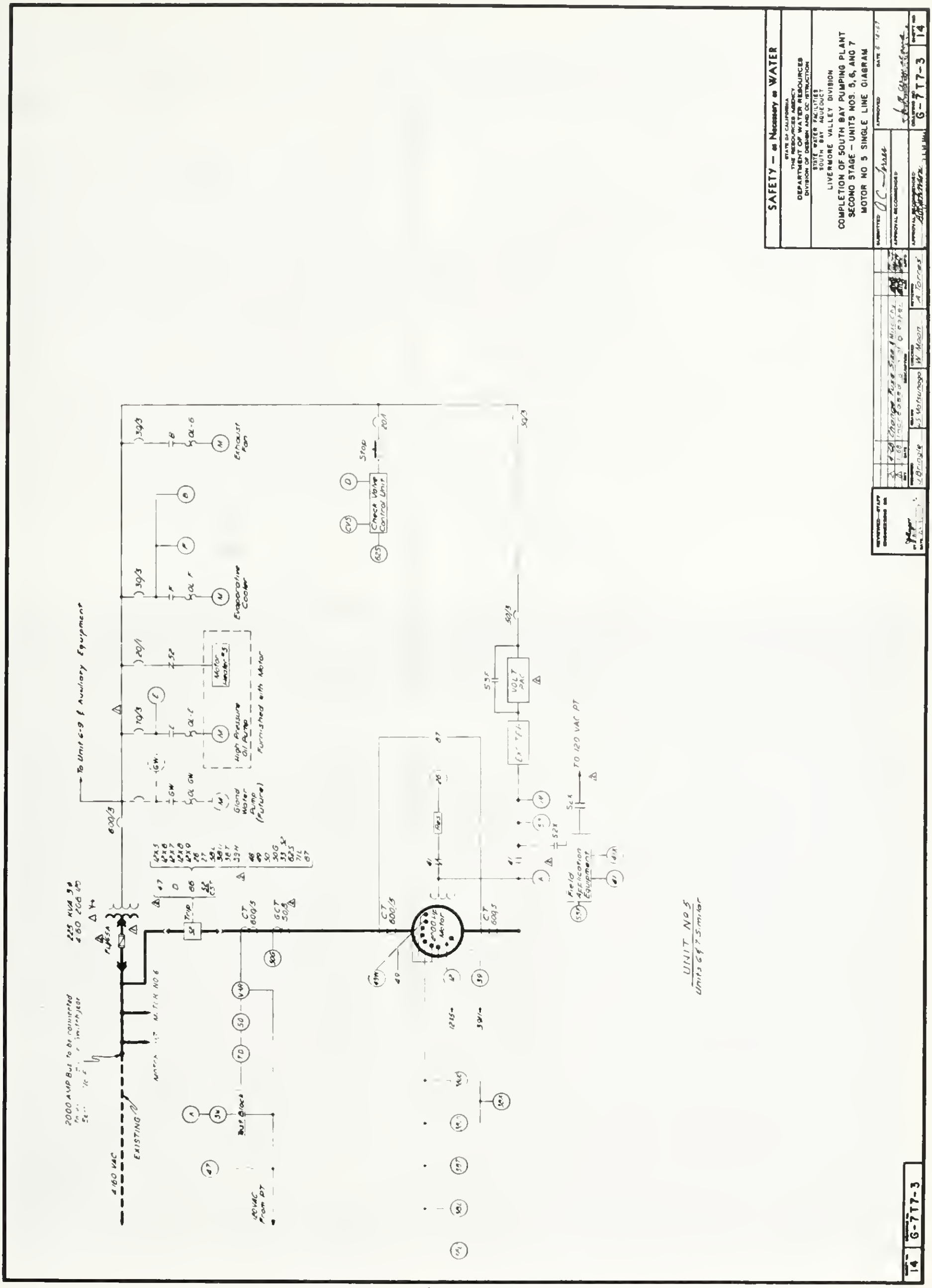

Figure 318. Single-Line Diagram—Unit No. 5

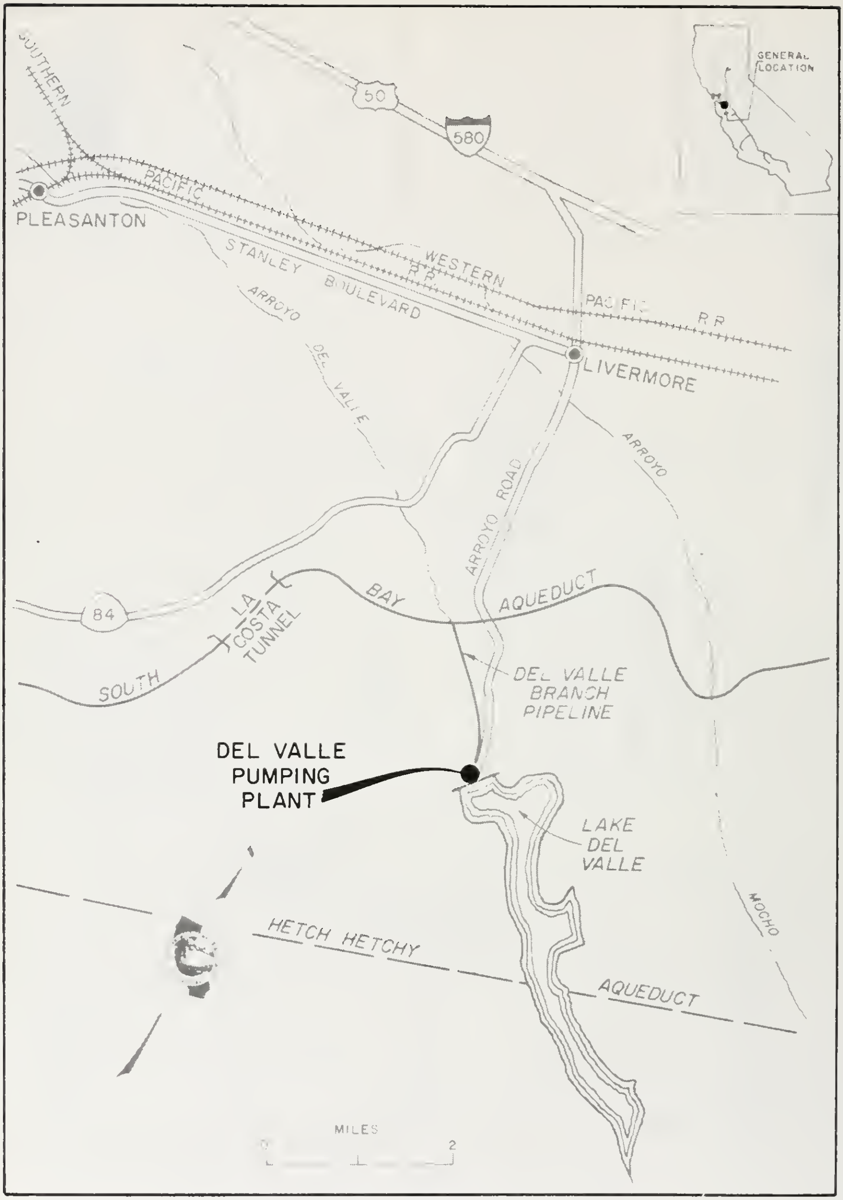

Figure 319. Location Map—Del Valle Pumping Plant

CHAPTER VI. DEL VALLE PUMPING PLANT

General

Location

Del Valle Pumping Plant is located immediately downstream of Del Valle Dam, which is approximately 4½ miles south of Livermore, California, just off Arroyo Road in Alameda County (Figures 319, 320, and 321).

Purpose

This plant is used to pump water during low demand periods from the South Bay Aqueduct into Lake Del Valle for storage and to convey water back to the Aqueduct when the demand is high. Actually, the plant serves as a booster station in the branch line between South Bay Aqueduct and the Lake (Figure 320).

Description

This plant is small compared with most of the other State Water Project pumping plants. Its dimensions are 30 by 100 feet, not including adjoining structures for valve pits and office wing. The substructure is reinforced concrete, and the superstructure consists of structural steel with precast, concrete, wall panels and metal deck roof. The plant houses four horizontal centrifugal pumps with a 30-cubic-foot-per-second capacity per unit, at a design head of 60 feet. Each pump is driven by a variable-speed electric motor rated 30 to 225 horsepower. Total plant capacity is 120 cubic feet per second (cfs). A 10-ton bridge crane is provided for installing and servicing plant equipment (Figure 322).

Representative drawings are included at the end of this chapter.

Figure 320. Del Valle Dam, Lake Del Valle, and Del Valle Pumping Plant

Figure 321. Del Valle Pumping Plant

Geology

Site Geology

Del Valle Pumping Plant foundation is within an old stream terrace underlain by bedrock. The terrace material is Recent alluvium, consisting of fine-grained sandy clay overlying sandy gravel. Beneath the alluvium are Cretaceous Panoche formation and Miocene Cierbo formation. Panoche formation consists of firm-to-slightly-soft sandstone with a few thin beds of firm shale. Cierbo formation consists of loose sandstone and slickensided siltstone and claystone. This formation includes swelling clays that are considerably softer than the Panoche. A shear contact between the two formations extends across the floor of the plant excavation. Other minor shears were exposed in the excavation. One shear on the south end of the west wall, in Panoche formation, distinctly separates distorted siltstone and claystone from friable sandstone. Most of the shearing is parallel to the bedding.

Geologic Exploration

Geologic exploration consisted of several spin auger holes, six rotary core holes, and a seismic refraction survey. A pitcher core barrel was used to obtain undisturbed samples for laboratory testing.

Instrumentation

Because the Pumping Plant is small and extensive surveillance instrumentation has been incorporated at Del Valle Dam nearby, no instrumentation is installed at the plant site.

Figure 322. Interior View of Plant

Seismicity

The Pumping Plant is in a seismically active region. Major faults in the area include the Calaveras 8 miles west, the Hayward 13 miles west, and the San Andreas 30 miles west.

Civil Features

Preliminary Studies

Studies for the plant siting were governed by the topography of the narrow canyon and alignment of the Del Valle Branch Pipeline. The site selected is adjacent to the outlet works service road, is approximately 900 feet from the toe of the Dam, and is about 1½ miles south of South Bay Aqueduct. Geologic exploration subsequently confirmed the adequacy of the foundation. After operational studies were complete, pumps were selected and plant size determined.

Site Development

Site development began in 1967 when the hillside at the site was graded level to provide approximately one acre of working area for the plant. An entrance road, 300 feet long, was constructed to connect the plant to the outlet works service road. Following excavation for and construction of the plant structure and manifold, the area was backfilled. Paving was placed around the plant as well as on the entrance road. A perimeter strip around the plant was landscaped. In addition to this work, a small switchyard and sanitary disposal field were constructed on the downhill side behind the plant. In 1969 chain-link fencing, with a gate at the entrance road, was installed around the entire site.

Plant Structure

Construction of the plant structure was accomplished under one contract. Under the same contract, all plant equipment, including four 30-cfs pumping units, was installed.

The plant substructure is built of reinforced concrete. Under the unit bays, a 3-foot-thick mat foundation with the base at elevation 580 feet was provided. This mat is founded upon moderately weathered claystone-sandstone material. At the northeast corner, where the formation dips below elevation 580 feet, overburden was removed and concrete backfill was placed to provide uniform bearing for the plant. Walls constructed at the perimeter of the mat extend the substructure to the ground floor at elevation 596 feet. Four concrete valve pits were built integral with the plant, one at each corner. These pits provide access to the valves that control the direction of pipeline flow. Manifold pipes extend through these valve pits and bypass the plant. At the south end of the plant are a service bay, office, toilet, and storage facility. The substructure for this part of the plant has a 6-inch concrete floor slab supported at the edges by a continuous concrete wall footing.

The superstructure is built with rigid steel frames which support the roofing, precast concrete walls, and a 10-ton bridge crane. The superstructure is 100 by 30 feet in plan and 29 feet - 3 inches in height. The adjoining wing structure for the office, toilet, and storage facility has concrete block walls with steel beams supporting the roof decking. This addition to the plant structure provides 770 square feet of floor space with a ceiling height of 9 feet.

Because of its location, this plant was designed to comply with the earthquake design provisions of the Uniform Building Code rather than the earthquake design criteria discussed in Chapter I of this volume.

Waterways

Waterways at Del Valle Pumping Plant include Del Valle Branch Pipeline which extends from South Bay Aqueduct (Del Valle Pipeline) to the Pumping Plant, a manifold at the plant, and a pipeline from the manifold to Lake Del Valle conservation outlet works. Del Valle Branch Pipeline is discussed in Volume II of this bulletin. Discussion in this chapter is limited to the manifold and the pipeline to the conservation outlet works.

This plant is basically a booster plant installed on Del Valle Branch Pipeline to pump water between South Bay Aqueduct and Lake Del Valle in either direction to meet operational requirements. The manifold is connected to the four pumps on both the intake and outlet sides. To accommodate gravity flow, a bypass line was provided around the plant perimeter. To provide control of flow in either direction, four butterfly valves were installed in pits located outside of and adjacent to the four corners of the plant.

Pumping into Lake Del Valle is required when the lake water surface is above the hydraulic gradeline of South Bay Aqueduct. Pumping is also required for flows from Lake Del Valle when the lake water surface is below the aqueduct hydraulic gradeline. Under some conditions, gravity flow will occur from the Lake to the Aqueduct and from the Aqueduct to the Lake.

The Del Valle Branch Pipeline system is capable of drawing down Lake Del Valle at a rate of 120 cfs until the lake water surface reaches elevation 639 feet, or filling the Lake at the same rate until the water surface reaches elevation 704 feet. Principal components of the conduit system, not including Del Valle Branch Pipeline, are the manifold and buried pipeline.

Manifold. The manifold consists of 60-inch-diameter steel pipes placed around the periphery of the plant, a 30-inch bypass pipe, four suction and discharge pipes, two 20-inch manhole nozzles, and appurtenant valves. The northwest corner of the manifold has a 60-inch by 60-inch steel pipe tee and a short section of 60-inch steel pipe that connects to Del Valle Branch Pipeline. The opposite or northeast corner has a similar tee connected to the 60-inch-diameter steel pipe which extends to Lake Del Valle conservation outlet works.

Two 60-inch sleeve couplings connected by a 7-foot-long pipe spool, located just outside of the plant foundation, were designed to accommodate differential settlement between the plant structure and adjacent pipes. Four 60-inch butterfly valves and sleeve couplings are located near each end of both manifold header pipes. These valves, together with one 30-inch valve on the bypass, control the direction of flow through or around the pumping units.

The manifold was constructed of ASTM A283C steel plate with welded joints. The entire manifold interior is coal-tar-lined. Earth-covered exterior portions are coal-tar epoxy-coated, and exterior portions exposed in vaults are coated with inorganic zinc silicate.

The 60-inch steel pipe in the manifold was designed as a buried pipe, with the maximum design head of 229 feet corresponding to elevation 773 feet, maximum water surface in Lake Del Valle.

Portions of the manifold piping outside of the plant are encased in concrete to resist the hydraulic thrust and to provide continuity with the plant structure.

Pipeline. The pipeline extends from the manifold to the Lake Del Valle conservation outlet works. It was constructed of ASTM A283C steel with double-welded lap joints and coal-tar lining and coating.

Appurtenances along the pipeline consist of a two-way Dall flow tube, an air valve and manhole structure, corrosion test stations, and cathodic protection devices.

The pipe backfill ranges from a 5-foot minimum to a 10-foot maximum.

Mechanical Features

General

The mechanical installation includes four pumps, four check valves, eight pump suction and discharge shutoff valves, one flow tube, four manifold valves, one bypass valve, one equipment-handling crane, and auxiliary equipment.

Equipment Ratings

Pumps

Manufacturer: Allis-Chalmers Manufacturing Co.

Type: Single-stage, split-case, centrifugal

Discharge, each:	30 cfs
Total Head:	60 feet
Speed:	variable
Horsepower, each:	250
Guaranteed Efficiency:	84.0%
Static Head (Variable):	0–38 feet

Check Valves

Manufacturer: Valve and Primer Corp.

Size and Type: 20-inch slanting disc

Discharge Valves

Manufacturer: BIF

Size and Type: 20-inch butterfly

Suction Valves

Manufacturer: BIF

Size and Type: 24-inch butterfly

Manifold Valves

Manufacturer: BIF

Size and Type: 60-inch butterfly

Bridge Crane

Manufacturer: Stryco Manufacturing Co.

Type: Overhead, traveling, bridge

Capacity: 10 tons

Pumps

Pumps are single-stage, split-volute case, horizontal-shaft, double-suction, centrifugal type connected to a horizontal-shaft, direct-current, variable-speed motor by a flexible coupling (Figure 323).

Pumps are used for reservoir lift or booster service depending on direction of flow through the manifold. Pumps rotate in a clockwise direction when viewed from the driver end and are started against a closed discharge valve.

The differential static head at the pump can vary from 0 to 38 feet depending on the water surface elevation in Lake Del Valle and the hydraulic gradeline of Del Valle Branch Pipeline. Because of the wide range of head, a direct-current motor is used with controls to provide infinite variation of pump speeds. With a proper combination of pumps and pump speed, the desired pumping rate can be achieved with certain limitations. The design of the system assumed that the minimum pump speed attainable is one-half the maximum speed. Any pumping rate below this speed

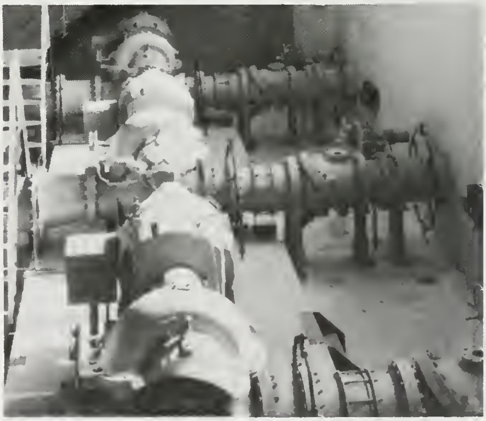

Figure 323. View of Pump Pit

range would be achieved by throttling the pump discharge valve. The characteristics of the split-case pumps are a continuously rising, stable head-capacity curve from 135% of rated discharge to shutoff head.

Pump Discharge Valves

A 20-inch-diameter, rubber-seated, butterfly valve with an electric operator was installed on the discharge side of each pump (Figure 323). They are used for throttling to obtain the proper flow when the flow rate cannot be accomplished by varying the pump speed (i.e., at low head conditions). These valves also are used as shutoffs to isolate each pump from its discharge line. The valves are closed during pump start-up and are opened when the control system pump set speed corresponds with the actual pump speed.

Check Valves

A 20-inch, slanting-disc, check valve was installed on the discharge side of each pump (between the pump and the discharge valve, Figure 323). The purpose of the check valves is to prevent or minimize the amount of reverse flow through the pump which could occur after a power failure. A large reverse flow could result in overtopping of the surge tank located on Del Valle Branch Pipeline. The check valves are equipped with a bottom-mounted snubber which prevents the disc from slamming.

Suction Valves

A 24-inch-diameter, manually operated, rubber-seated, butterfly valve was installed on the suction side of each of the four pumps. The purpose of these valves is to isolate the pumps from the manifold.

Manifold Valves

Four 60-inch-diameter, rubber-seated, butterfly valves with electric operators are installed in the plant manifold and are used for changing the direction of flow and for bypassing the pumps for gravity flow.

A 30-inch-diameter, rubber-seated, butterfly valve with an electric operator is installed in a 30-inch bypass line that bypasses one 60-inch manifold valve and is used to control the rate of flow by throttling during gravity flow to or from Del Valle reservoir.

Equipment Handling—Crane

The crane is an electric, overhead, traveling, bridge type powered by 208-volt, 3-phase, 60-hertz motors with floor-operated pendant controls. It is used for assembly and maintenance of plant equipment.

Capacity	10 tons
Span	27 feet—1/8 inch
Hoist hook lift	30 feet—2 inches
Speed (two)	3.3 or 10 feet per minute

Electrical Features

General

The electrical installation includes motors, switchgear, station service, protective relaying, and auxiliary systems for protection of equipment and personnel. Since the plant is not of sufficient size to require extensive electrical systems, the descriptions of electrical features for the larger plants in Chapter I of this volume are not directly applicable to this plant.

Description of Equipment and Systems

One 3-phase transformer, with its fuse and lightning protection, was installed to reduce the utility company voltage from 12 kV to 480/277 volts (Figure 324). Power is distributed at 480 volts through a cabinet lineup which contains all controls and protection for the plant except the graphic control panel.

Four motors are direct-current, variable-speed, with silicon-controlled rectifier units and static exciters. Fuses protect the motor and the motor field with a circuit breaker installed in the circuit to the motor, field, and silicon-controlled rectifier unit. The plant is operated by local control.

Equipment Ratings

Motors

Manufacturer: General Electric Company

Type: Horizontal, direct-current, variable-speed, armature-controlled

Horsepower: 250 at 720 rpm

Speed range: 360 to 720 rpm

Motor field: 250 volts, direct-current

Power Transformer

Manufacturer: General Electric Company

Volts: 12,000–480Y/277

Taps: In the high-voltage winding, 2½ and 5% above and below rated voltage

Phase: 3

Capacity: 1,000 kVA

Type: OA

Connections: Delta-Wye

Station Service

Volts: 480–240/120

Phase: 1

Capacity: 50 kVA

Reliability of Service

Lake Del Valle is an integral part of the water system connected to this plant. Maximum reliability, therefore, is not required for the plant's electrical equipment and systems because of the back-up provided by the Lake. A single 3-phase transformer was selected as well as single circuits and equipment for all station service. All equipment is standard with re-

22—87370

placement parts readily available. The 12-kV transformer can be transported, repaired, and returned within a few days in event of failure. The required reliability did not justify more elaborate equipment.

System Control

Since the head variation exceeds the operational ability of a single-speed pump, a variable-speed drive direct-current motor was selected. Because the motor cannot operate at all necessary speeds, the valves are throttled under certain head conditions. The control system operating zones show the system complexity. Variables in the system are number of pumping units, motor speed range, and percent throttling of discharge valves. Maximum efficiency and minimum pump cavitation were the objectives in establishing the operating zones.

The control system is operated by first establishing the plant's pumping requirements. After the operator determines reservoir level and head on the plant, the number of units is established and their speeds set. In the event the reservoir level is low, throttling of the discharge valves is required and percent closure is determined and set.

Computer operation of the system was originally planned but subsequently deferred. Due to the many variables involved, it was decided to operate the equipment manually until experience was gained on the system.

The operator controls the pump units and valves from a graphic display and control panel (Figure 325). The discharge valve position also may be adjusted to suit the reservoir level and pumping needs. Other valves throughout the water conveyance system also may be operated from the panel.

Motor Control Equipment

The power conversion units utilize silicon-controlled rectifiers and diodes which provide adjustable direct-current voltage to the motor armatures. Current-limiting fuses, surge protection, and static suppression circuits protect the motor and operating equipment (Figure 326).

A solid-state field excitation system with silicon-type rectifiers also is provided. Fuse protection is installed in the alternating-current power supply to the system.

Power Factor Correction

Capacitors were initially installed to maintain the power factor of each motor circuit within 90%. After the equipment had been placed in operation, internal wiring of the controls overheated and burned, and the capacitors failed. Investigation revealed that a resonant circuit had developed with one of the harmonics of the 60-Hz power supply. The capacitors were found unnecessary, and the equipment has since operated satisfactorily without their replacement.

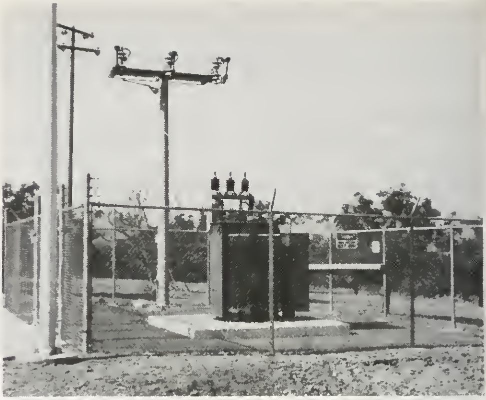
Figure 324. Transformer Yard

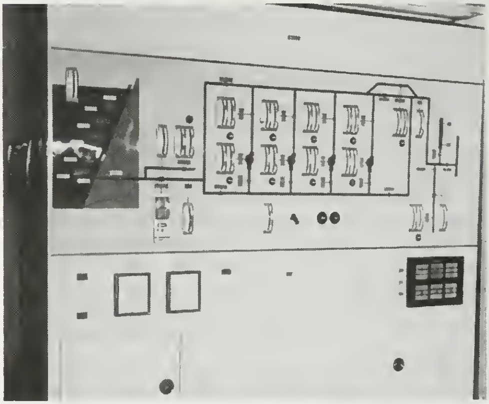
Figure 325. Graphic Display Panel

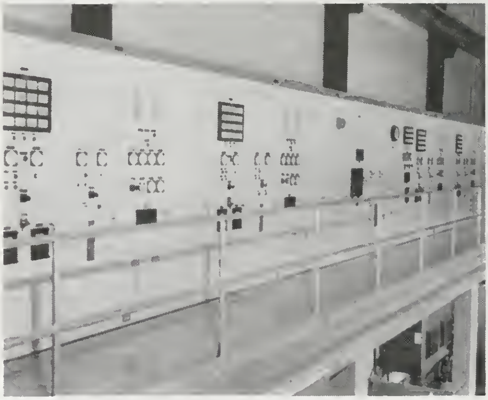
Figure 326. Power and Motor Control Equipment

TABLE 6. **Major Contracts—Del Valle Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Pumps	67-15	$79,052	$83,843	$833	3/27/67	12/12/69	Allis-Chalmers Mfg. Co.
Pumping plant	67-38	765,154	845,307	53,669	9/26/67	11/24/69	Cortelyou and Cole Inc.
Motors and controls	67-46	162,974	275,557	97,735	12/27/67	12/15/69	L.C.L. Controls

Construction

Contract Administration

Del Valle Pumping Plant was constructed under the provisions of Specification No. 67-38. The work included construction of the plant structure, manifolds and intake pipeline, and switchyard; and the installation and testing of pumps, motors, electrical equipment, and controls furnished by the Department of Water Resources. General information for the major contracts is shown in Table 6.

Clearing and Grubbing

Clearing and grubbing of the plant site was a relatively minor operation consisting of removal of oak and walnut trees and disposal of grass and brush.

Site Excavation

A Gradall was used for the greater portion of foundation excavation for the substructure of the plant (Figure 327). Material too dense for the Gradall to remove was excavated with a Hopto excavator. All material removed was hauled by two 22-cubic-yard dump trucks to a spoil area off the job site. At elevation 581 feet (approximately 1 foot above the excavation lower limit), a 2-foot-deep gravel deposit was encountered along the northeast corner of the excavation. This deposit was removed within the limits of the foundation and replaced with backfill concrete to elevation 580 feet.

A Traxcavator was used for the parking lot and roadway excavation. The excavated material was temporarily stockpiled and later hauled to a waste area near Livermore.

Trenches for the grounding grid at elevation 580 feet were excavated 6 inches into the foundation with a small backhoe and backfilled with compacted clayey material locally obtained.

Pneumatic mortar was applied to the exposed plant foundation base surface to elevation 580 feet (Figure 328).

Foundation Slab Concrete

The building foundation slab was constructed in two concrete placements of approximately equal yardage. A vertical construction joint was placed in the center of the slab. Electrical conduit and substructure plumbing embedments were made and tested in conjunction with placement of the two bottom mats of reinforcing steel (Figure 329).

Figure 327. Completed Foundation Excavation

Figure 328. Foundation Excavation Showing Pneumatically Applied Mortar

Concrete for the foundation slab was hauled to the site in transit mix trucks and placed by the crane-bucket method. Concrete was cured by continuous wetting of burlap blankets placed over the concrete.

Foundation Wall Concrete

Formwork for the 13-foot-high foundation walls was a patented type that eliminated vertical studding and utilized precut, wedge-type, tie rods to ensure uniform wall thickness. Four placements were required. Because of the great amounts of plumbing and electrical embedments in the east wall, some difficulty was experienced in placing the concrete until "pencil" vibrators and ¾-inch maximum aggregate were used. Considerable time and effort were spent by the contractor in finishing the inside wall face. The surfaces were ground, and any rock pockets occurring under the embedments were repaired with epoxy concrete.

Figure 329. Foundation Slab Reinforcing Steel, Plumbing Embedments, and Sump Pit

Valve Pit and Manifold Concrete

The contractor elected to support the manifold on concrete piers placed along its length at approximately 5-foot intervals. Prior to encasement of the manifold, the contractor filled it with water to prevent flotation.

Figure 330. 60-Inch Manifold "T" Encasements

Installing 60-Inch Pipeline

The 60-inch pipeline, running from the Lake Del Valle conservation outlet works to the plant, was placed in an excavated trench. Since this piping was supplied in 40-foot lengths, it was not necessary to delay the placement of backfill material between the bell and spigot joints until the joints were welded. Backfill material was placed initially to the springline. Welding of the bell and spigot joints was tested with an 80-pound-per-square-inch air pressure. Interior welds then were coated with coal-tar epoxy and outside welds were sandblasted, primed, and wrapped with coal-tar tape.

Backfill was consolidated by jetting with water and vibrating with 3½-inch internal vibrators to a relative density of 70%. Consolidated backfill material was then placed to ground level to a relative compaction of 95%.

Installing Pumps, Valves, and Motors

All four 60-inch valves were installed within a period of one week. Concrete encasement of both the north- and south-end manifolds was completed after placement of the 60-inch valves and manifolding was completed (Figure 330). Installation of pumps and motors took 3½ months (Figure 331).

Figure 331. Delivery of Pumps

Other Construction

Other construction, including the pumping plant superstructure and crane, the electrical installations, and the access roads, was routine.

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 332 through 346).

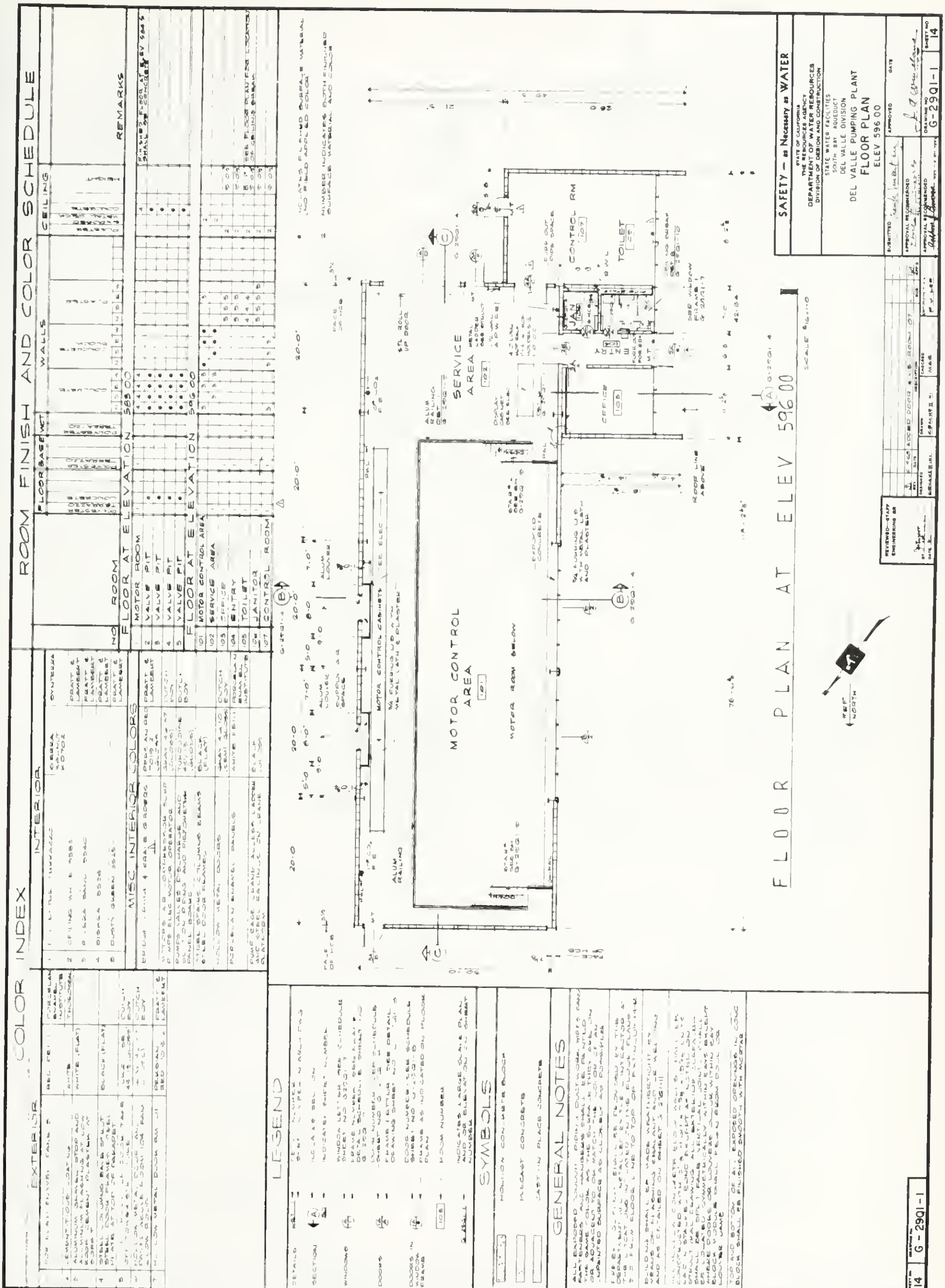

Figure 332. Floor Plan—Elevation 596.0

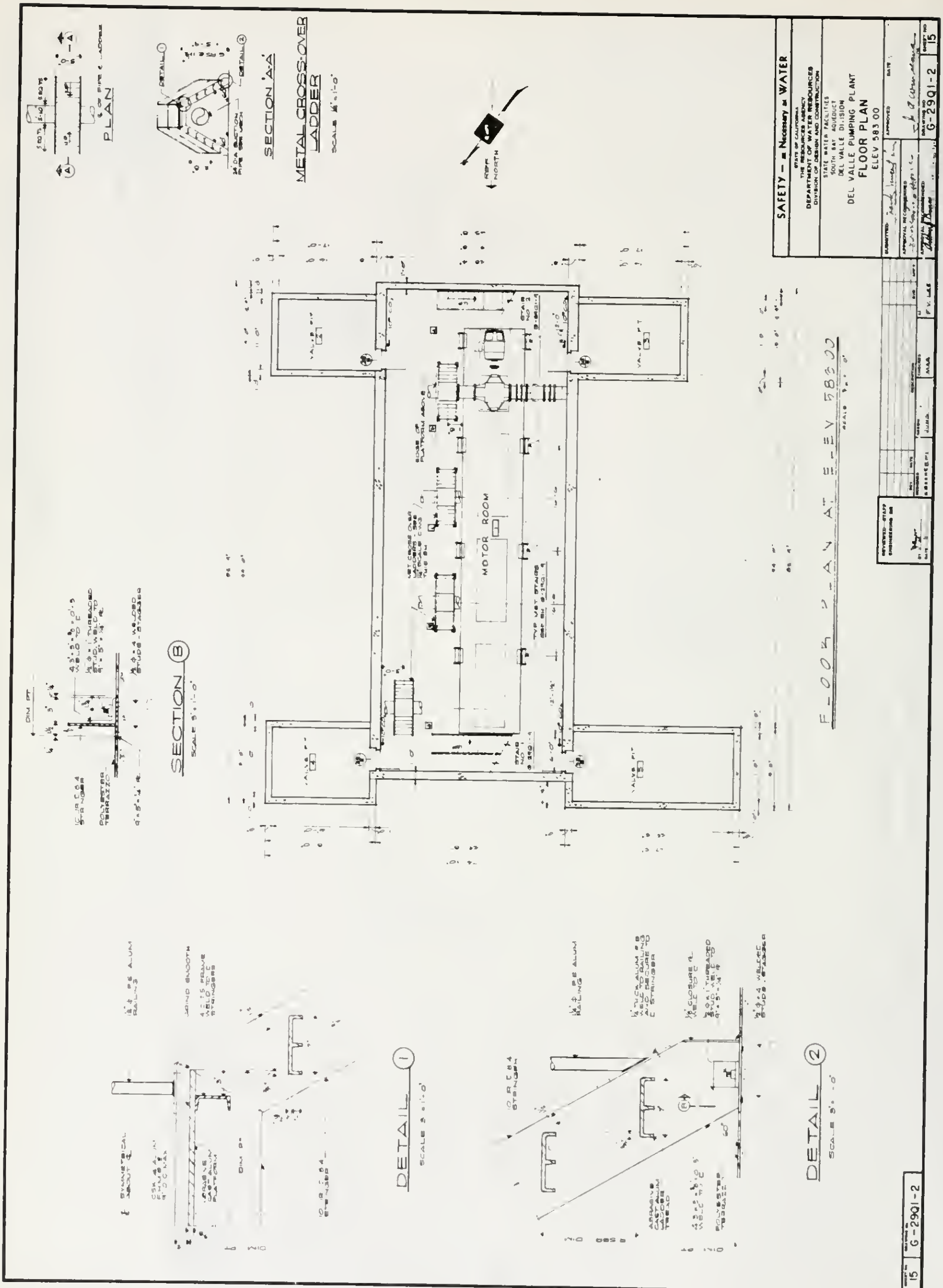

Figure 333. Floor Plon—Elevotion 583.0

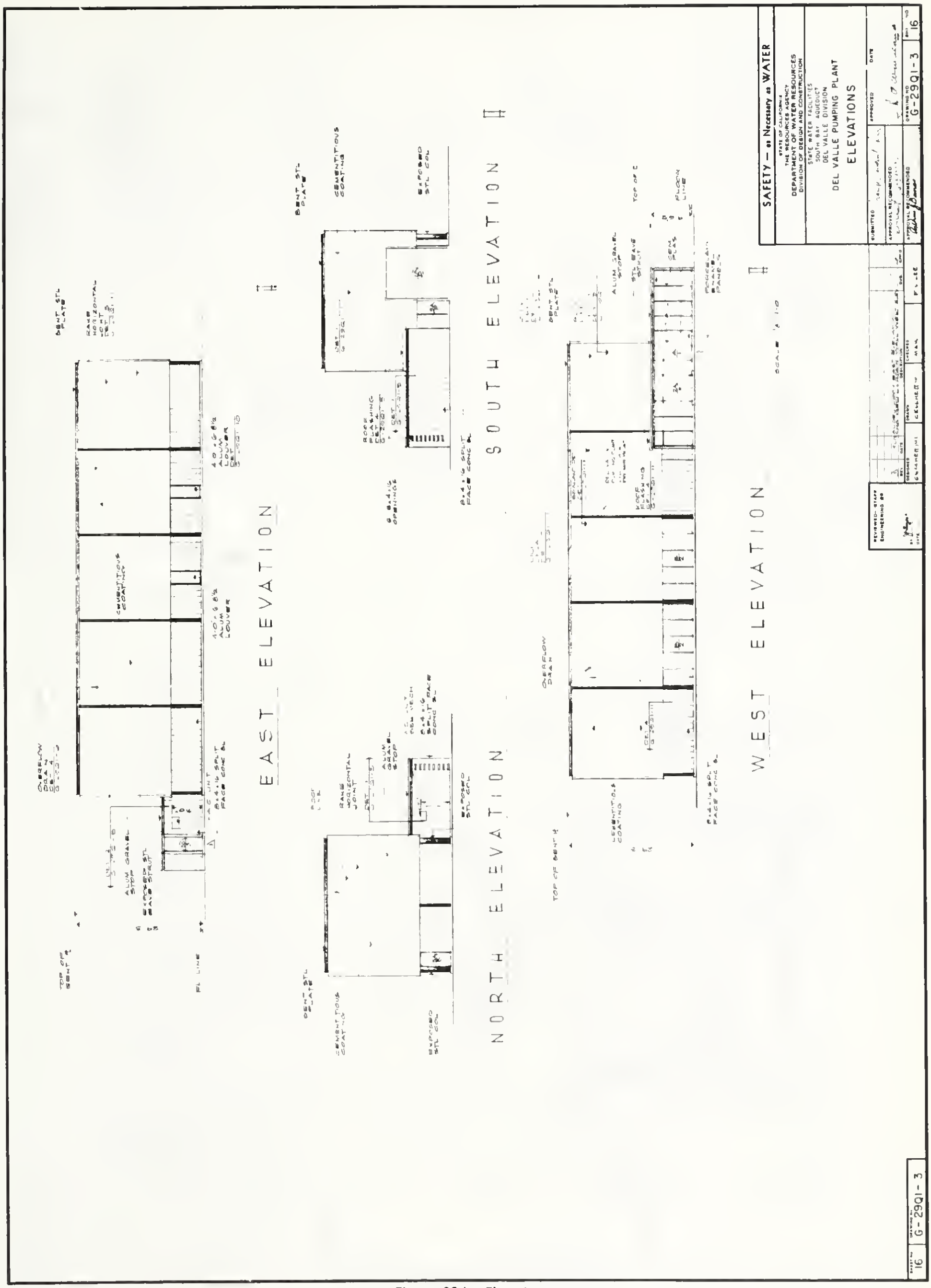

Figure 334. Elevations

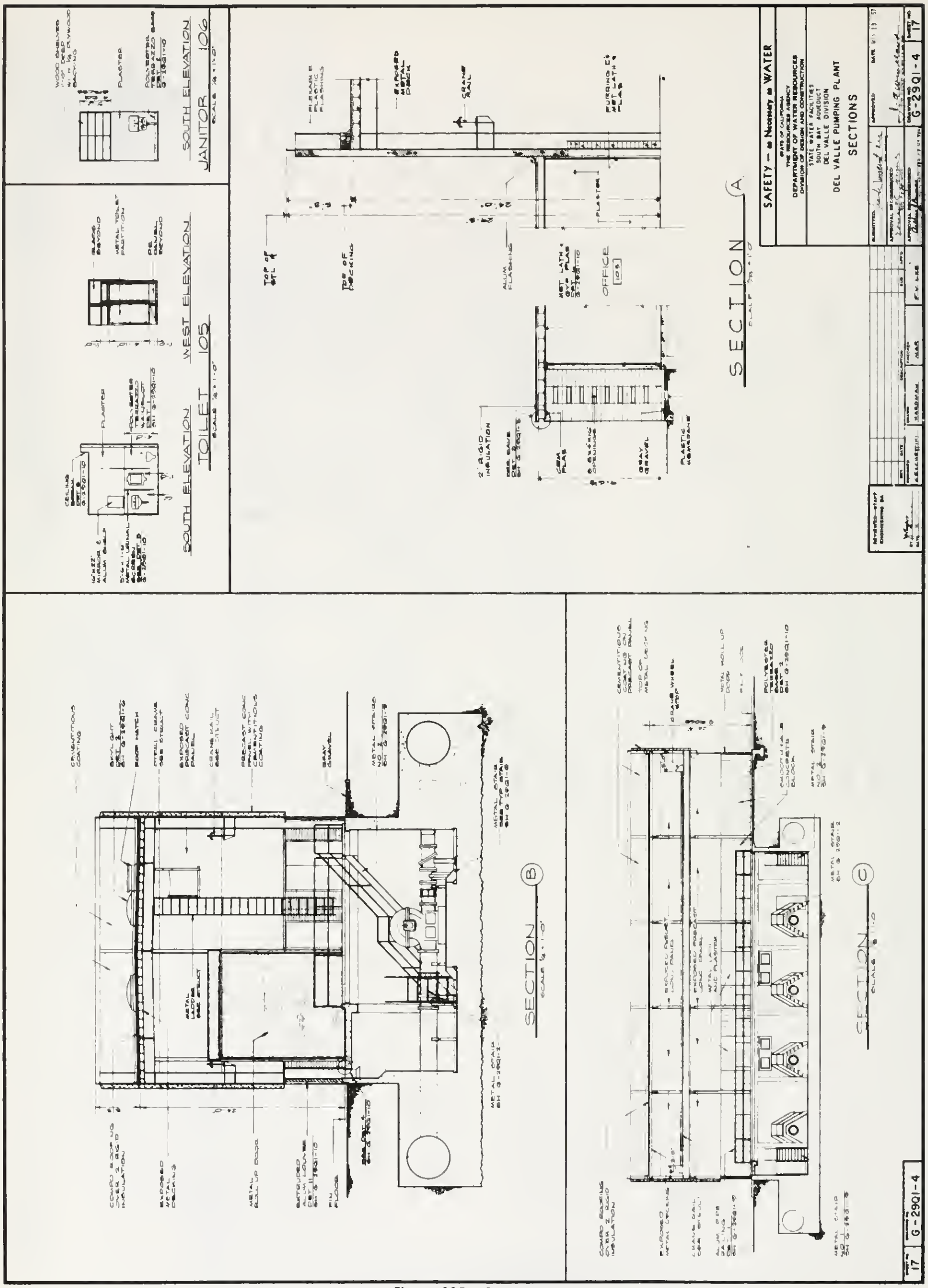

Figure 335. Sections

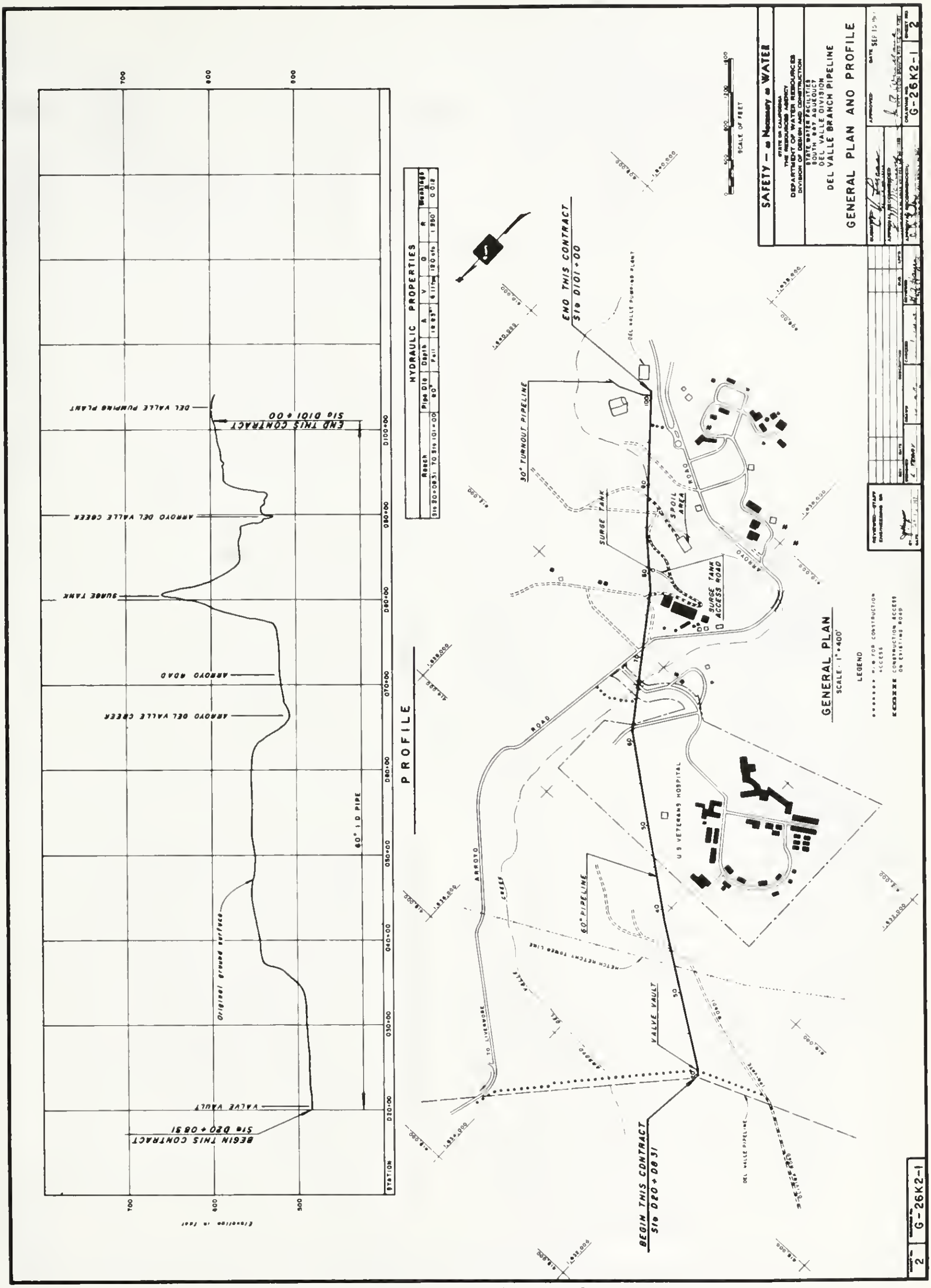

Figure 336. General Plan and Profile

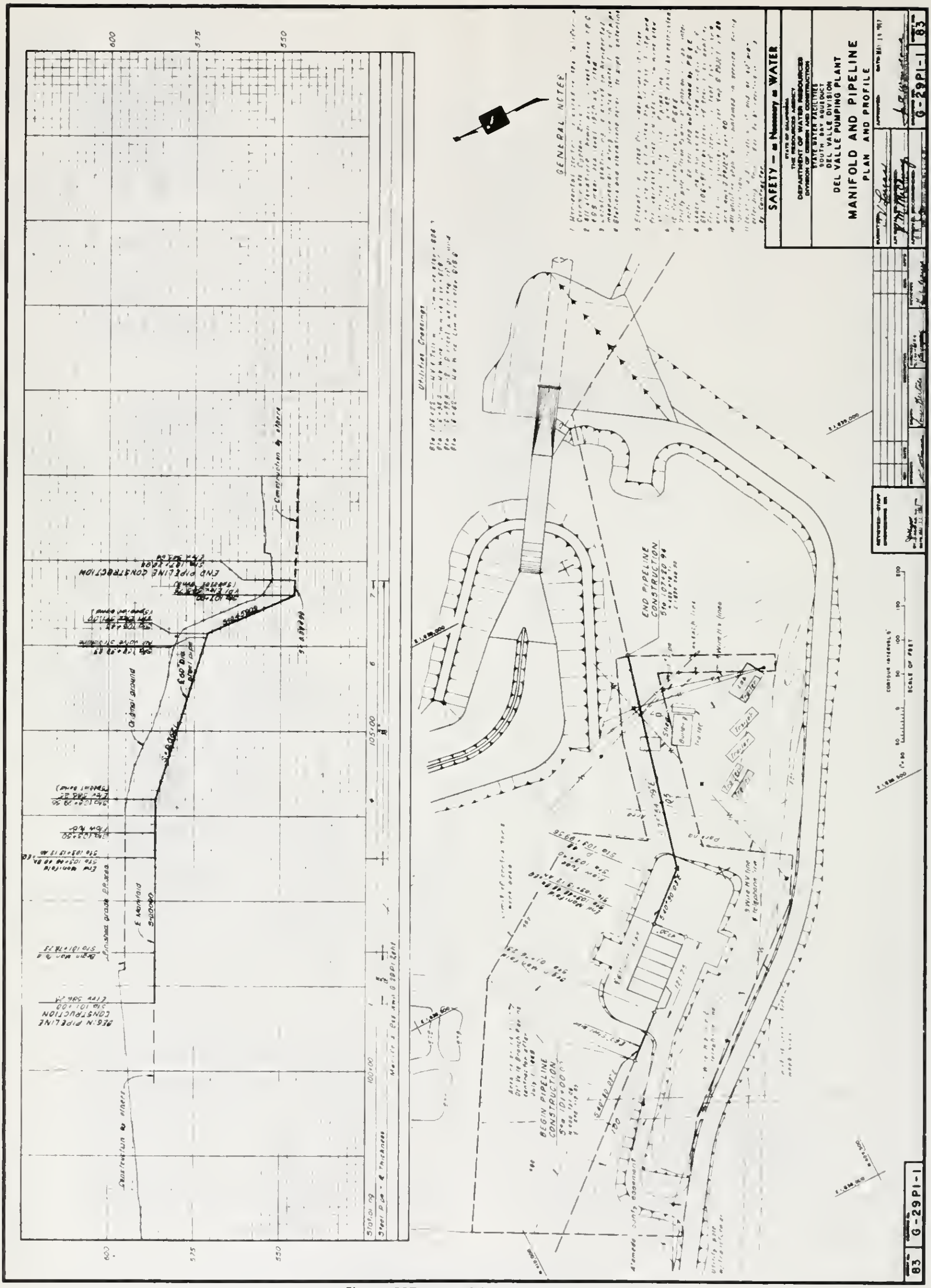

Figure 337. Manifold and Pipeline

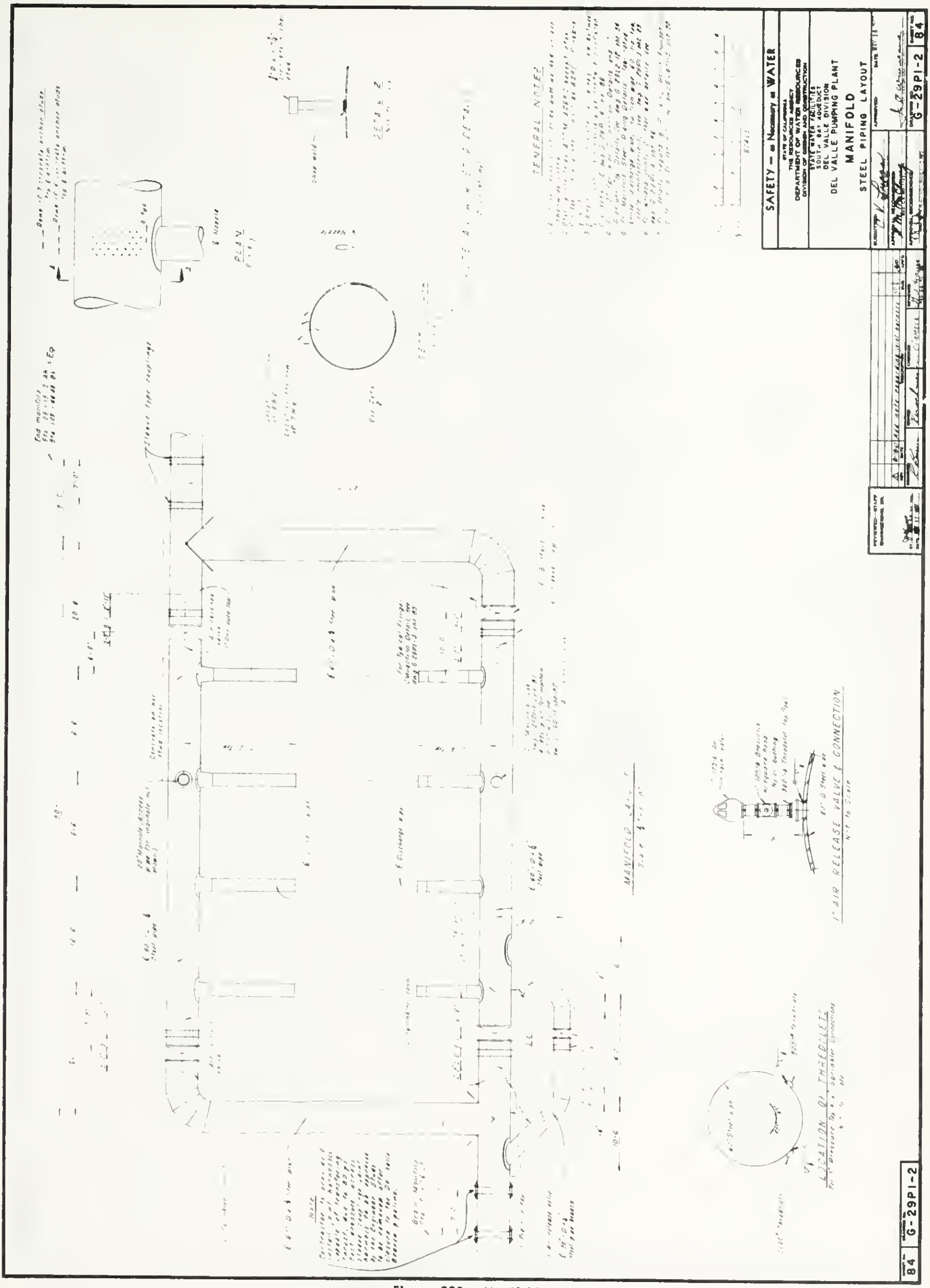

Figure 338. Manifold

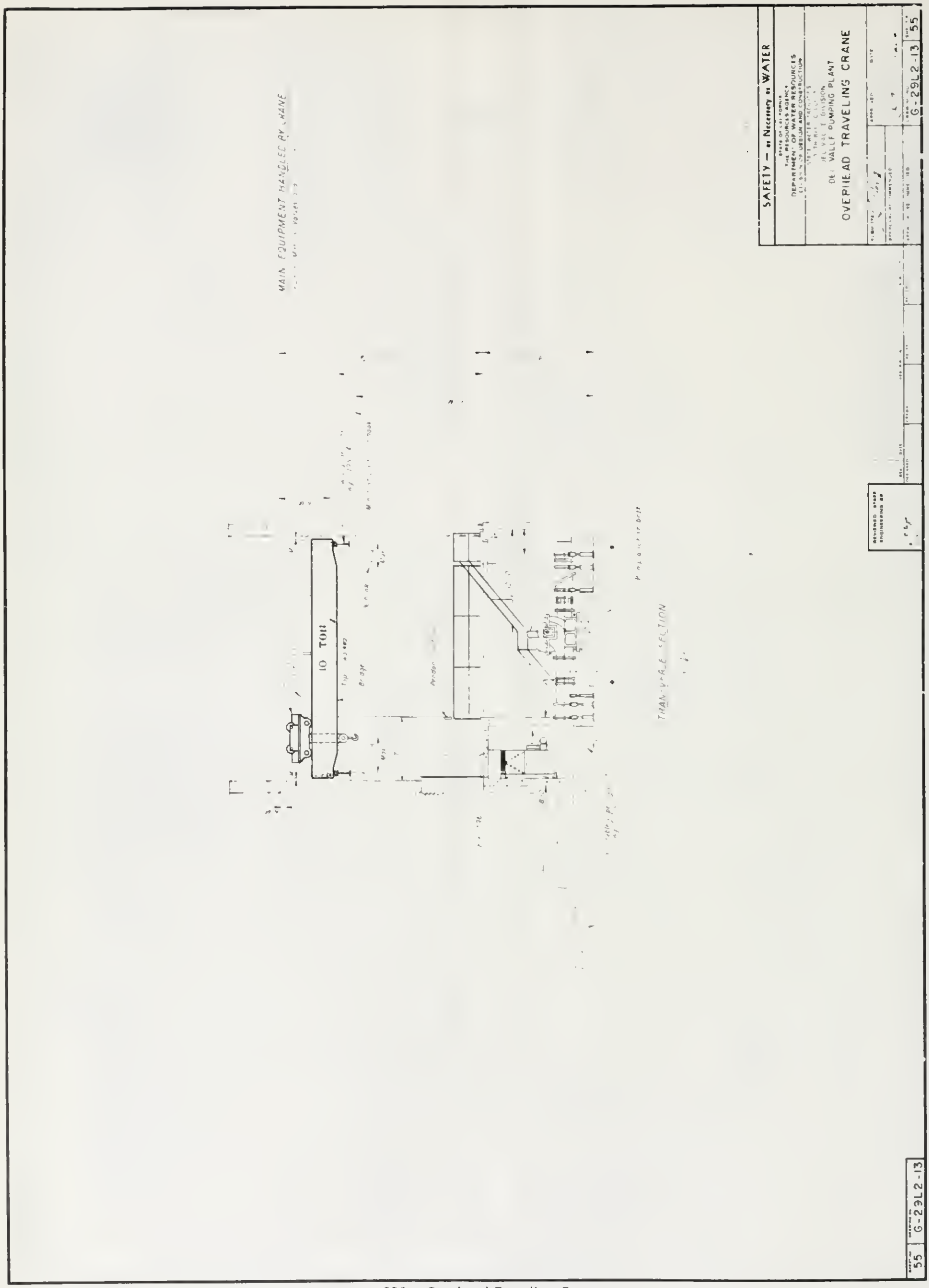

Figure 339. Overhead Traveling Crane

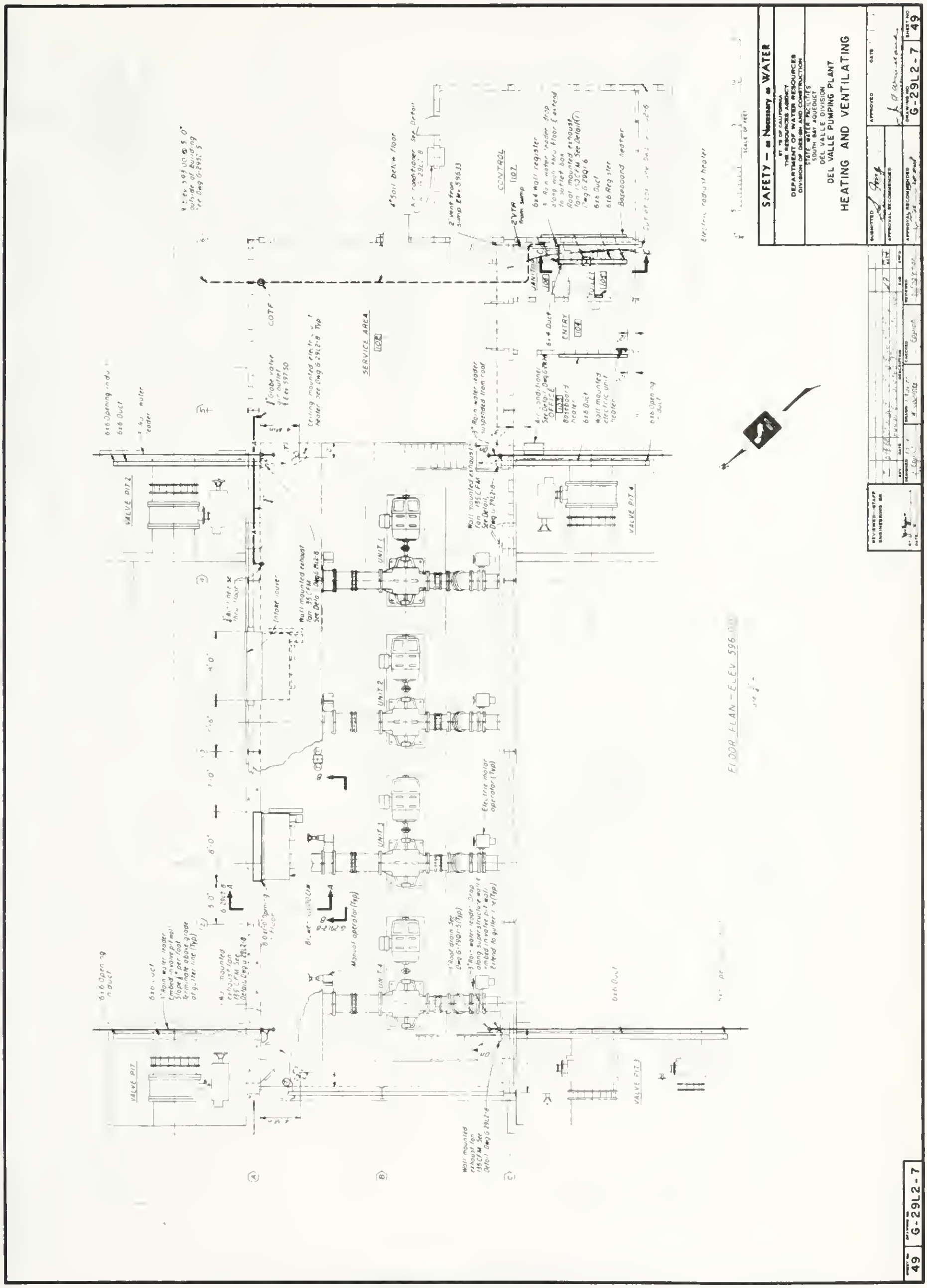

Figure 340. Heating and Ventilating

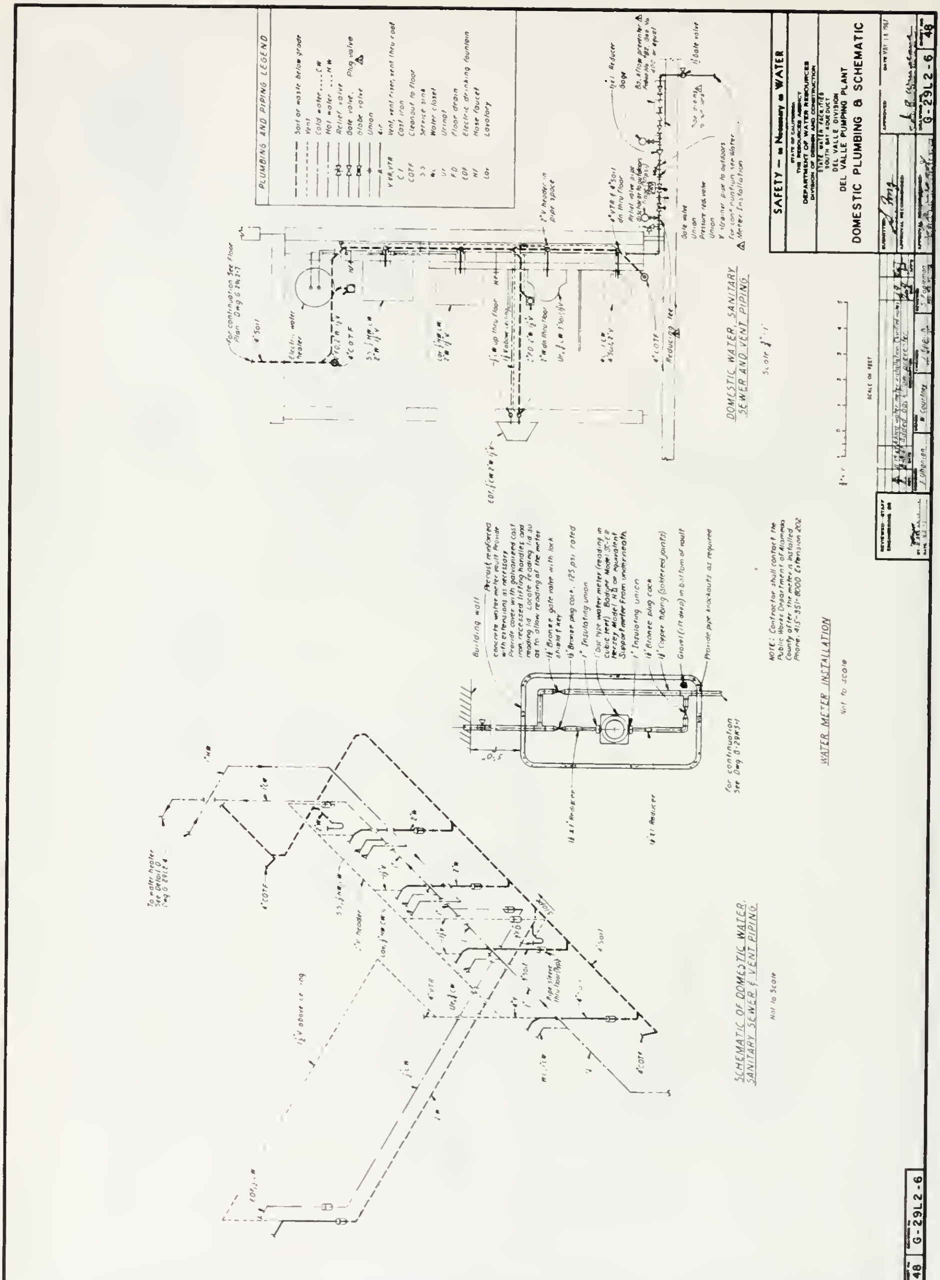

Figure 341. Domestic Plumbing

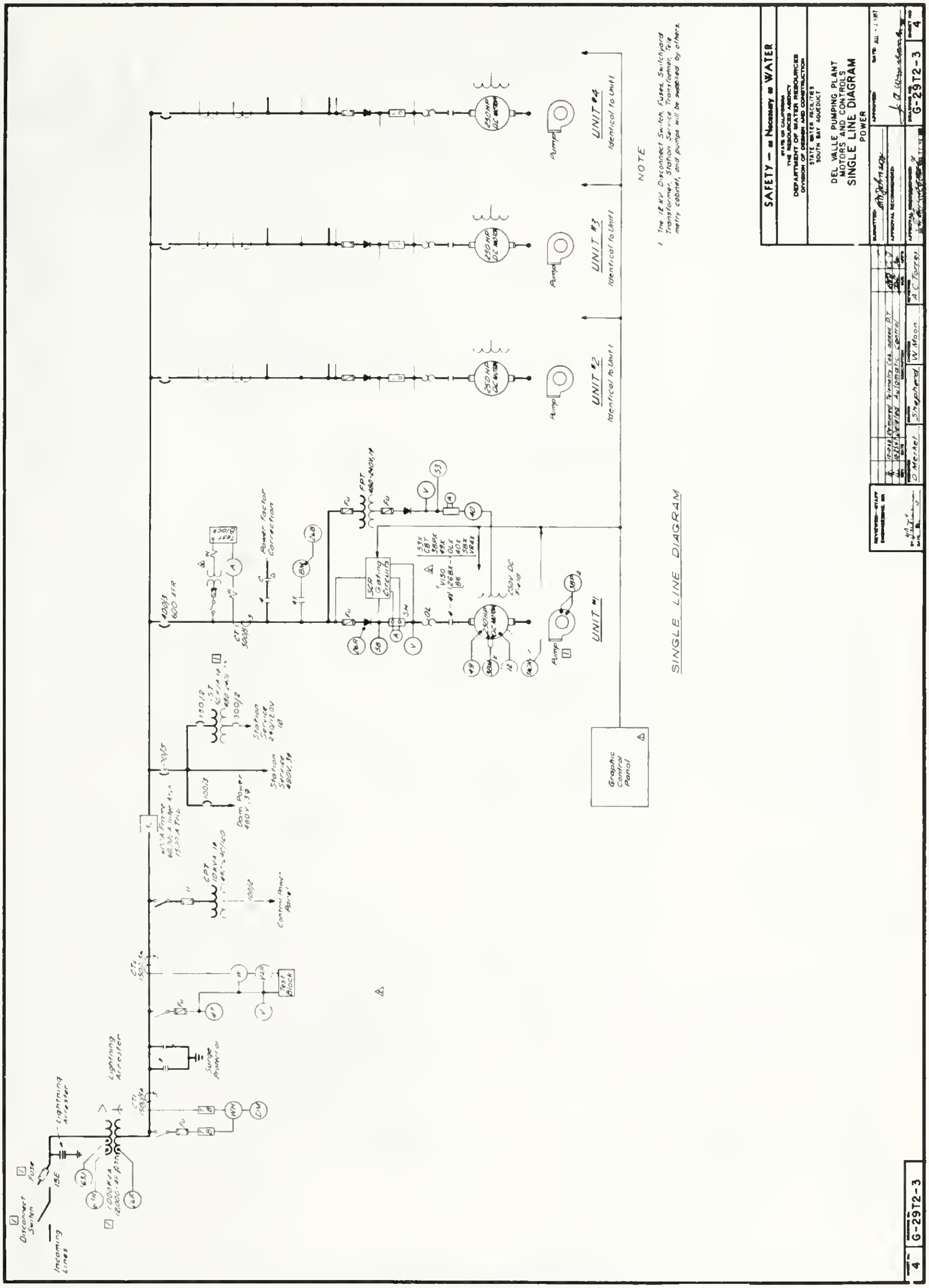

Figure 342. Single-Line Diagram

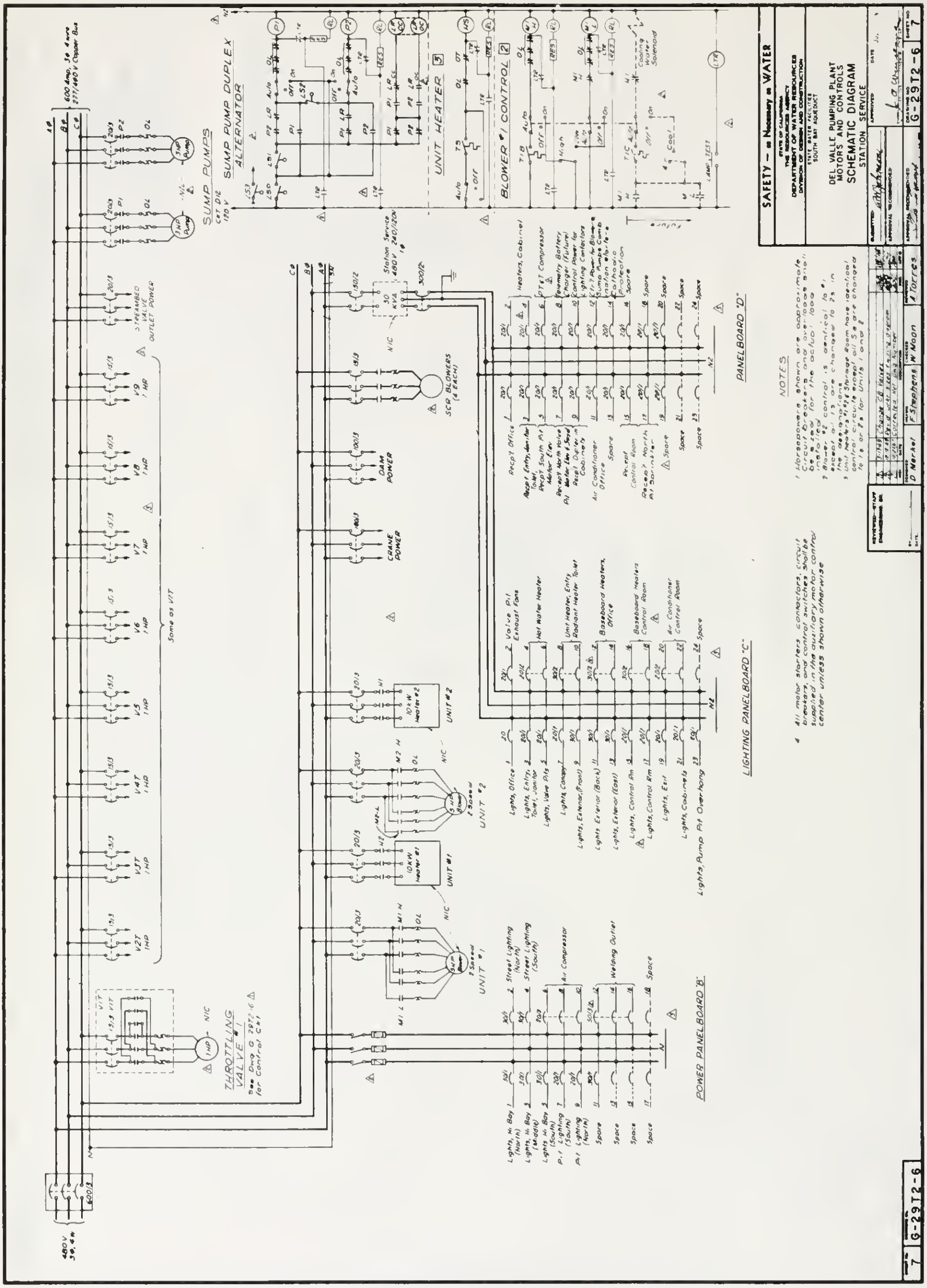

Figure 343. Station Service Schematic

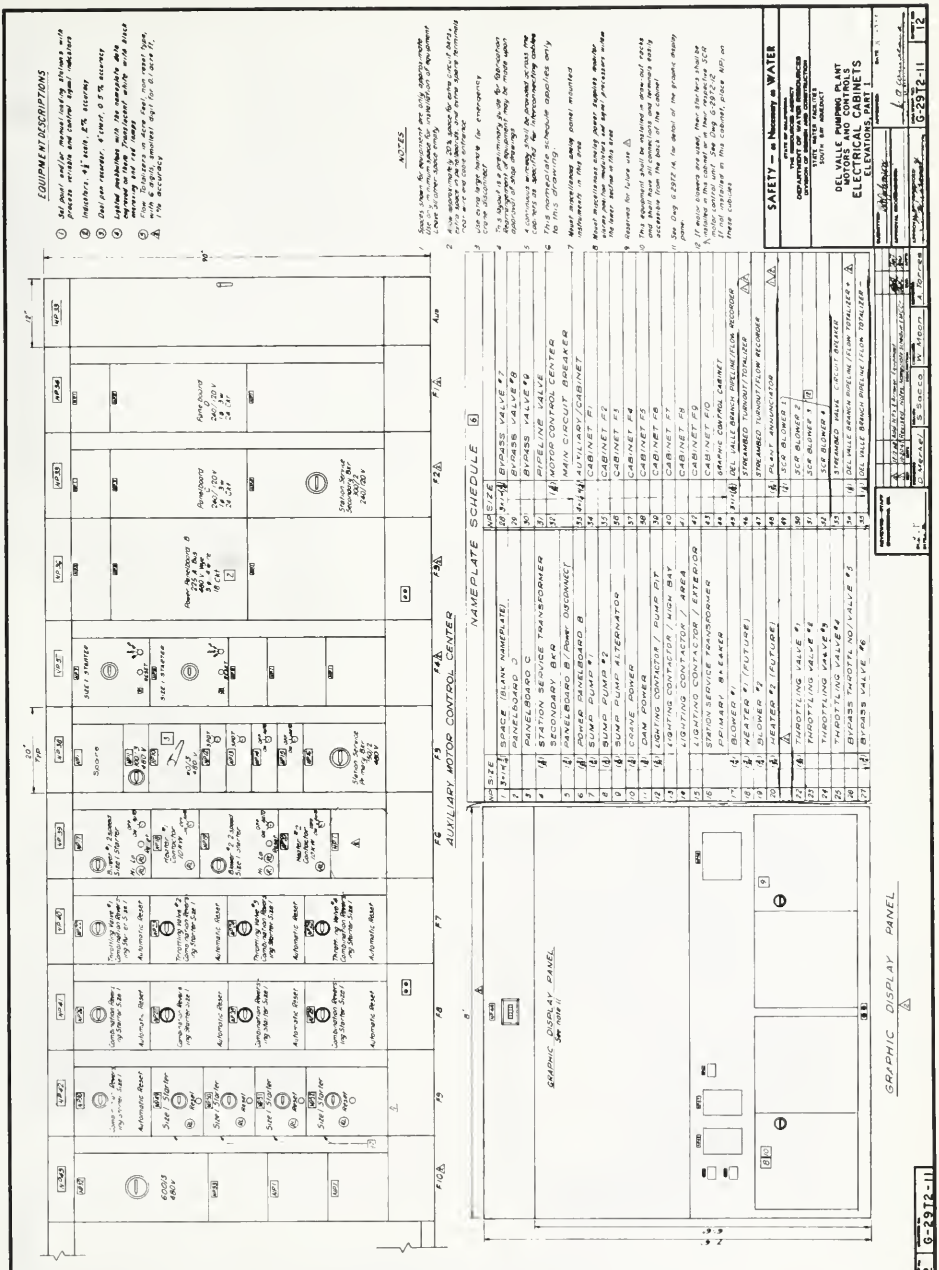

Figure 344. Electrical Cabinets

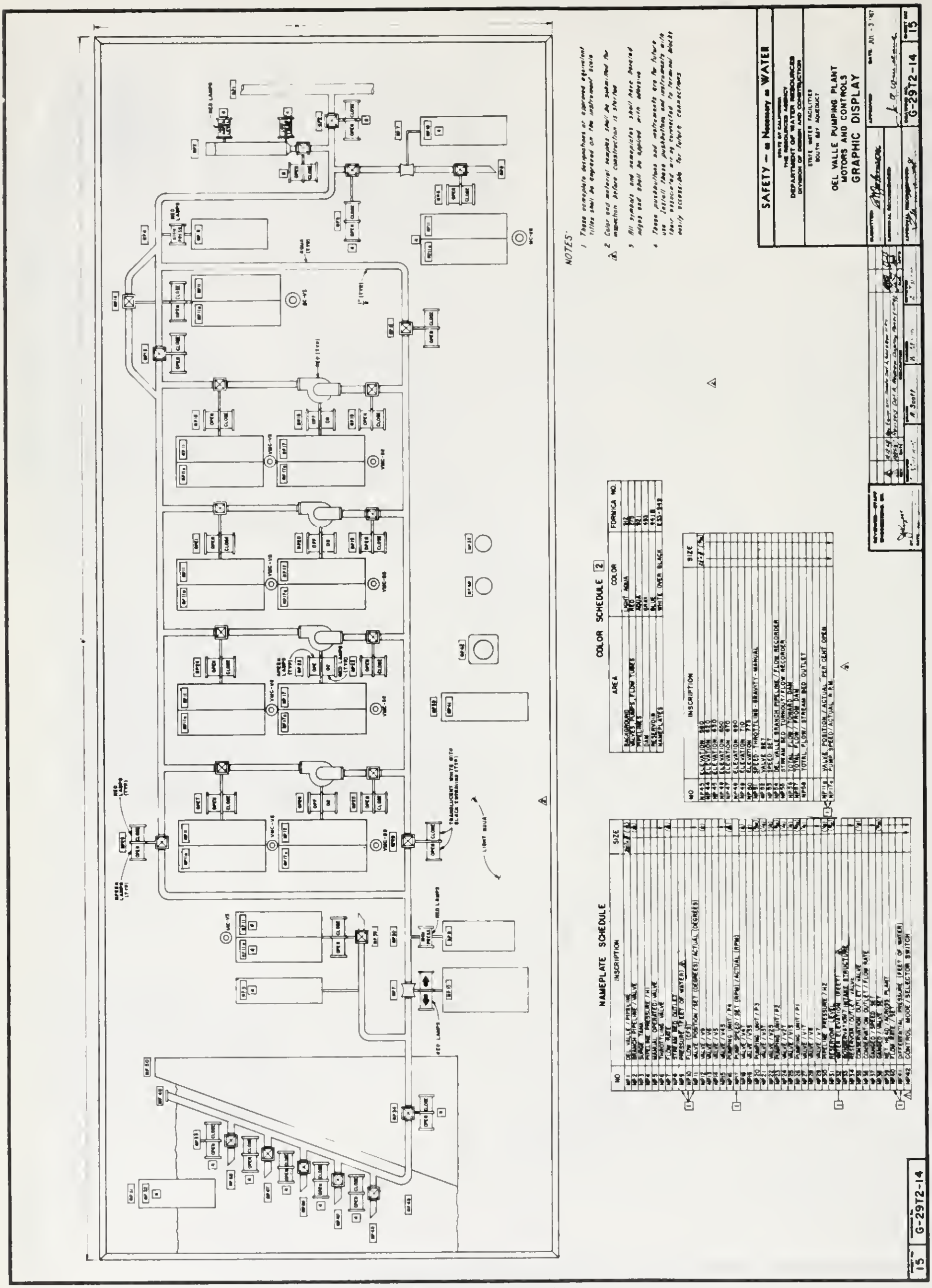

Figure 345. Graphic Display

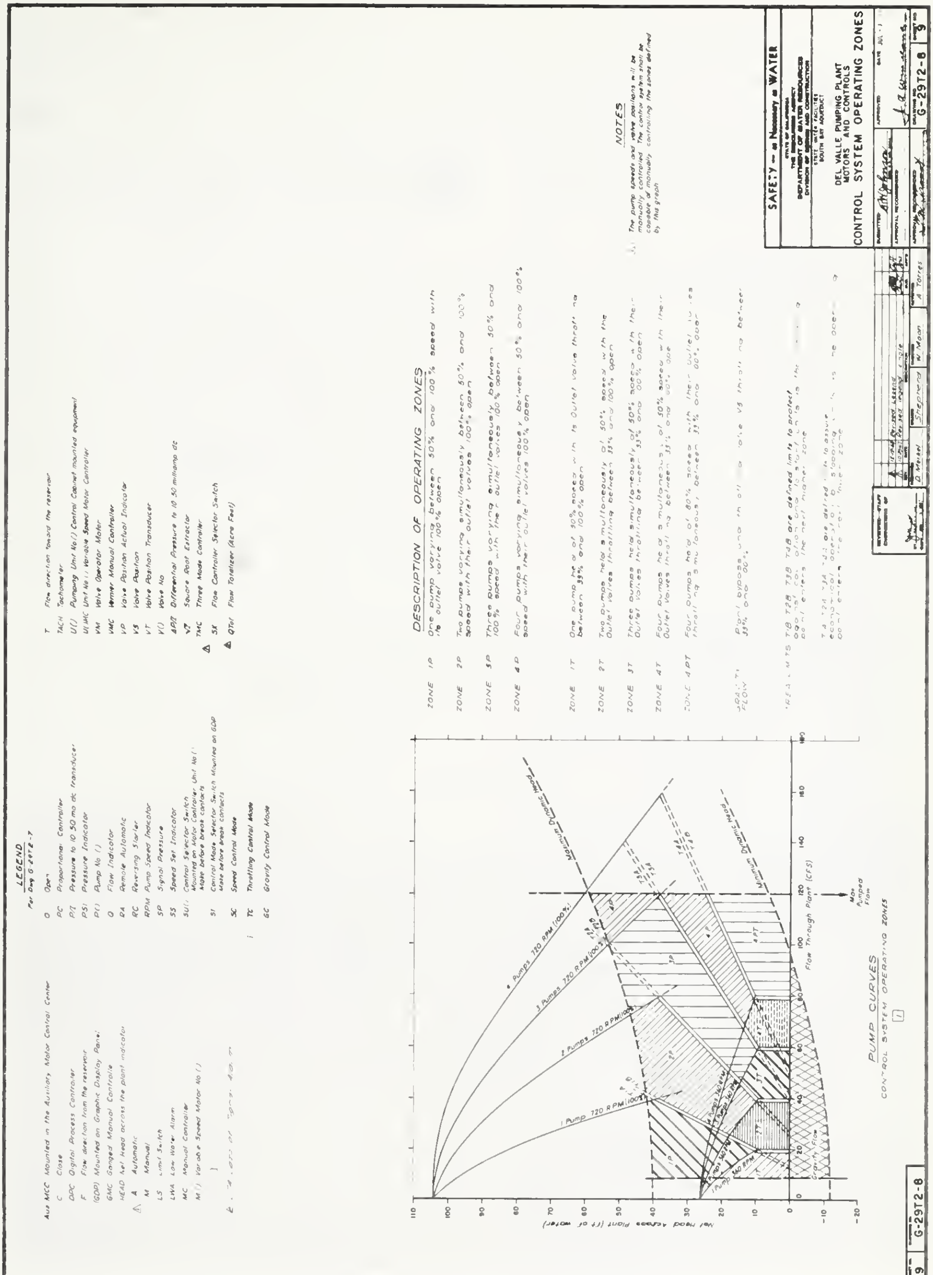

Figure 346. Control System Operating Zones

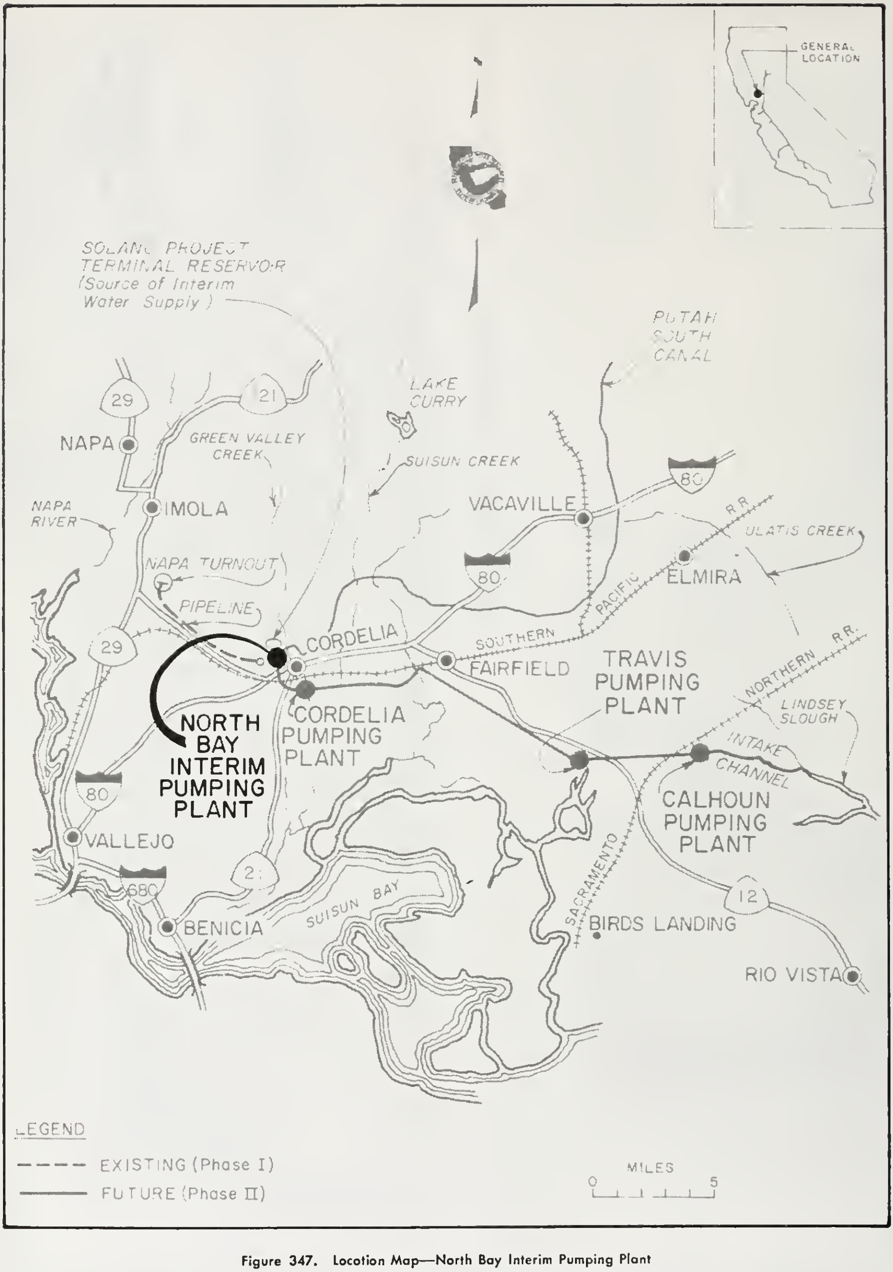

Figure 347. Location Map—North Bay Interim Pumping Plant

CHAPTER VII. NORTH BAY INTERIM PUMPING PLANT

General

Location

North Bay Interim Pumping Plant is located in Solano County approximately 15 miles northeast of Vallejo and 1.1 miles northwest of Cordelia Junction on Interstate Highway 80. The plant is adjacent to Solano Project Terminal Reservoir, a U.S. Bureau of Reclamation project. Access to the plant is via Green Valley Road and the Bureau of Reclamation's Putah South Canal operating road (Figures 347 and 348).

Purpose

The purpose of the Pumping Plant is to lift water supplied from Solano Project Terminal Reservoir and deliver it to Napa Turnout Reservoir. The delivery to Napa Turnout Reservoir is made through the interim discharge pipe and Napa Pipeline (Figure 347). The staged construction of the North Bay Aqueduct is discussed in Volume II of this bulletin.

This pumping plant and discharge pipe will be removed from service and replaced by permanent facilities (about 1980). The temporary supply of water from the Solano Project Terminal Reservoir fulfills the Department of Water Resources' contract with the Napa County Flood Control and Water Conservation District. The permanent water supply for North Bay Aqueduct will come directly from Lindsey Slough in the Sacramento-San Joaquin Delta.

Figure 348. North Bay Interim Pumping Plant

Description

This facility is an unattended outdoor-type plant with four pump units of the following capacities: one rated 2,600 gallons per minute (gpm); one 3,500 gpm; and two at 4,300 gpm each, one of which is a spare. A maximum of 10,400 gpm (23 cubic feet per second) is lifted 319.5 feet. The combined horsepower required is 1,800. The area around the plant is paved and enclosed by an 8-foot chain-link fence. Within this area is the 60-kV switchyard and a 10- by 24-foot wooden building for electrical-mechanical equipment (Figure 349).

Representative drawings are included at the end of this chapter.

Geology

Site Geology

The plant foundation is alluvium consisting mostly of fat sandy clay. Underlying the alluvium is residual soil and fractured volcanic rocks of the Sonoma Volcanics formation. The Sonoma Volcanics, which have been folded and highly fractured, include basalt and andesite flows and tuff beds.

Geologic Exploration

Three rotary holes were drilled by a special track-mounted rotary drill. Two holes were drilled to a depth of 14 feet and one to a depth of 26 feet. All three holes were terminated in bedrock. An auger hole was drilled near the site for the interim intake pipeline.

Instrumentation

Because of the small plant size, no instrumentation for monitoring structural performance was installed.

Seismicity

This area is considered seismically inactive.

Civil Features

Site Development

Some of the factors that were considered in establishing the size of the site were:

1. Minimum amount of imported backfill materials required.
2. Minimum turning area needed for maintenance trucks.
3. Size of concrete slab foundation needed for pumps and motors and transformers.
4. Size of switchyard and storage and maintenance building.

Field inspection indicated that a clayey soil under the plant was unsuitable for adequate bearing and drainage. Soil samples were tested for consolidation and swelling. This clay is highly plastic, is difficult to remold, and requires approximately 4 feet of overburden to prevent swelling when it becomes saturated. Since the soil was unsuitable for bearing and drainage, the existing soil was excavated and replaced with 3 feet of select permeable material and an 18-inch-thick concrete slab.

To protect the plant foundation from seepage, a subsurface drainage system was installed. The subsurface drainage system consists of select permeable material ($\frac{3}{8}$-inch to $\frac{3}{4}$-inch crushed rock) and a 6-inch-diameter, perforated, corrugated-metal pipe. A paved drainage ditch was provided around the site perimeter to control surface runoff.

Plant Structure

This small plant consists of four pumps and motors supported on a 20- by 56-foot concrete foundation. The concrete foundation for the pumps, motors, and electrical transformer was designed to minimize vibration. The 18-inch-thick foundation slab also serves as overburden load to prevent the soil from swelling when saturated. The foundation is 4 feet thick on the discharge manifold side, with additional thickness being required to balance the vertical thrust acting on the steel thrust anchors.

Waterways

Intake Facilities. The outlet extension from Solano Project Terminal Reservoir was installed by the Solano Irrigation District. It is a 42-inch-diameter concrete pipe approximately 200 feet long which extends from the Solano Project Terminal Reservoir to a multiple outlet. The intake structure to this pipe has a trash screen that is maintained by Solano Irrigation District. The multiple outlet provides connections for the Department and other agencies to take water from the Reservoir. The connection for the interim facility is a 10-foot extension of 30-inch-diameter steel pipe. Ninety feet of 30-inch steel pipe leads from this connection to the plant's intake manifold.

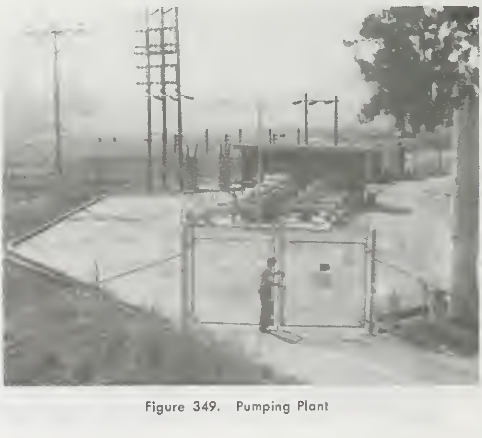

Figure 349. Pumping Plant

Located near the beginning of the intake pipeline, a vent structure protects the intake pipeline and the reservoir outlet extension from damage which could result from the high pressures caused by concurrent failure of the pumps and check valve.

Manifold Section. The plant intake manifold proportions flow from the intake to the pumps to maintain a uniform velocity to each pump. The discharge manifold conveys the flow to the interim discharge line after it has passed through the pumps. The discharge manifold design pressure is 225 pounds per square inch (psi), which includes the total dynamic head plus a 50% water-hammer allowance.

Steel pipes of standard sizes were used for the suction and discharge manifolds. Sleeve-type couplings were provided for installation and to allow for differential settlement.

Pump Discharge Pipe. The pumping plant discharge pipeline extends from the plant discharge manifold to the Cordelia Surge Tank. This 24-inch, buried, steel pipe is 2,474 feet long. The unlined pipe has welded joints and is coated with coal-tar enamel. The entire pipeline was structurally designed to withstand the soil load and an AASHO Class H20-S16 live load.

Mechanical Features

General

The mechanical installation includes four pumps, four pump discharge valves, one flowmeter, and auxiliary equipment.

Chapter I of this volume contains information on the mechanical equipment for other plants of the State Water Project; however, most of this information generally does not apply to this plant. This is a relatively small plant intended to provide an interim water supply until permanent facilities are constructed. Unique characteristics of the plant are included in the following description:

Figure 350. Pump Discharge Valves, Pumps, and Motors

Equipment Ratings

Pumps

Manufacturer: Worthington Pump Co.

Type: Horizontal-shaft, split-case, single-stage, centrifugal

Pumps Nos. 1 and 2	
Horsepower, each:	500
Discharge, each:	4,300 gpm
Total Head:	353 feet
Speed:	1,775 rpm
Pump No. 3	
Horsepower:	450
Discharge:	3,500 gpm
Total Head:	353 feet
Speed:	1,775 rpm
Pump No. 4	
Horsepower:	350
Discharge:	2,600 gpm
Total Head:	353 feet
Speed:	1,775 rpm
Pump Discharge Valves	
Manufacturer:	Darling Valve Manufacturing Co.
Type:	Spherical, single-seat
Size:	10-inch and 12-inch
Design Pressure:	520 feet
Operating Time:	10–50 seconds
Hydraulic Operating System Pressure:	1,000 psi
Pump Inlet Valves	
Manufacturer:	Darling Valve Manufacturing Co.
Type:	Gate
Size:	14-inch
Design Pressure:	150 psi
Operation:	Handwheel

Pumps

The pumps are horizontal, single-stage, double-volute, centrifugal type, directly connected to horizontal-shaft induction motors (Figure 350).

One 4,300-gpm pump is a standby for any one of the other units. For the two smaller size units, the flow is matched by discharge valve throttling. Total delivery is 10,400 gpm which is a combination of Units Nos. 3, 4 and either 1 or 2.

A fly wheel mounted between each pump and motor is used to control hydraulic transients caused by emergency power outages. The fly wheels provide part of the WR^2 (lb-ft^2) required to keep the surges from exceeding the design limits.

Pump Discharge Valves

Each pump is provided with a discharge shutoff valve for unit starting, stopping, and isolation for inspection and maintenance. The valves are fixed single-seated spherical type with hydraulic cylinder operators. They were designed to sustain the maximum transient pressures without exceeding allowable design stresses.

The valve operating system consists of 1,000-psi, nitrogen-charged, piston-type accumulators; sump;

Figure 351. Discharge Valve Hydraulic Control Console

pumps; valves; piping; and controls as required (Figure 351).

Flowmeter

A 24-inch Dall flow tube meter is installed in the intake pipe complete with a flow transmitter, flow indicator, recorder, and totalizer (Figure 352).

Electrical Features

General

The electrical installation includes controls, motors, switchgear, station service, and protective relaying. Since this plant is much smaller in capacity than most of the other plants in the Project, electrical systems are significantly different than those described in Chapter I of this volume.

Description of Equipment and Systems

The four motors are operated from a 2,300-volt bus, being controlled and protected by starters and current-limiting fuses. Capacitors are installed with each motor to improve power factor.

Four single-phase transformers, one a spare, receive the 60-kV power supply for reduction to 2,300 volts. They are connected on both the high and low side to external bus for convenience of connections (Figure 353). Lightning arresters and fuses protect the transformers from abnormal transmission line conditions.

Surge protection is provided on the 2,300-volt bus by lightning arresters and capacitors. Revenue metering and single-phase station service connections are also made to this bus.

Protective relays, instruments, operating meters, and local controls are provided. This equipment is located inside the control building in the metal-clad switchgear with the motor controllers.

Equipment Ratings

Motors

Manufacturer: Louis Allis Company
Type: Horizontal-shaft, squirrel-cage, induction, weather-protected type II
Phase: 3
Frequency: 60 Hz
Volts: 2,300

Motors Nos. 1 and 2

Horsepower, each: 500
Speed: 1,780 rpm
Power factor: 95.5% with 50-kVA capacitor

Motor No. 3

Horsepower: 450
Speed: 1,775 rpm
Power factor: 95.5% with 75-kVA capacitor

Motor No. 4

Horsepower: 350
Speed: 1,775 rpm
Power factor: 96.0% with 75-kVA capacitor

Power Transformers

Volts: 60,000–1,386
Taps: In the high-voltage winding, 2½ and 5% above and below rated voltage
Phase: 1
kVA: 500
Type: OA

Station Service

Volts: 2,400–240/120
Phase: 1
kVA: 25
Type: Dry

Figure 352. Pump Flow Indication and Recording Console

Figure 353. 60-kV Transformer Yard

Figure 354. 2,300-Volt Motor Control Equipment

Interim Facility

The Pumping Plant will be replaced in about 1980 as explained at the beginning of this chapter. Electrical equipment and systems were selected for a permanent, rather than a temporary, plant. Reliability of operation and safety considerations to both equipment and personnel precluded designs with less than a permanent-type installation. Although the motors and power transformers are located outdoors, a building was provided for all other electrical equipment (Figure 354). This provides protection for the equipment and better maintenance conditions.

Motors and Controllers

Selection of induction motors and starters with current-limiting fuses was made primarily because of costs. Costs for synchronous motors, controls, and protection were greater than for the selected equipment, and savings more than offset the somewhat higher power costs. Since the plant was designed for unattended operation, minimum maintenance was one of the factors considered in the selection of induction motors.

Power Transformers

Four single-phase transformers were selected. Economics and reliability were important considerations used in making this choice. Other possibilities were either one or two 3-phase transformers. The loss of the plant for the time necessary to repair a failure to a 3-phase unit would be excessive. The selected arrangement allows the spare single-phase transformer to be connected, both high and low sides, to replace any other transformer without moving the spare.

Station Service System

A single system of 240/120 volts, single-phase, was selected for the station service system. No back-up equipment or circuits were supplied. The small size of the plant allowed savings in cost with this minimum system. All equipment is of standard manufacture and in industry stock, readily available in major cities nearby.

Construction

Contract Administration

Construction of the Pumping Plant, appurtenances, and discharge line and installation of the pumps, motors, and related equipment were included in the contract designated Specification No. 67-25. The pumps and motors were furnished by a separate contract in accordance with Specification No. 67-09. General information for these contracts is shown in Table 7.

TABLE 7. **Major Contracts—North Bay Interim Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Pumps and motors	67-09	$78,146	$70,701	--	3/10/67	1/30/69	Worthington Corp.
Plant, discharge lines, and installation	67-25	224,437	276,212	$24,444	8/31/67	1/ 7/69	Cabildo Corp.

Excavation and Fill

Excavation from a designated borrow area was required for fill material for the plant site and for the access road between the Solano Project Terminal Reservoir and the plant site (Figure 355). The contractor used two small 15-cubic-yard scrapers to excavate and haul the material to the fills. Compaction of the in-place material was by a grid-type roller.

The trench for the 24-inch, steel, discharge line was excavated by a backhoe with a ¾-cubic-yard-capacity bucket (Figure 356). No rock was encountered, and excavation was completed with little difficulty.

Structure excavation was performed with a small backhoe and finished by hand.

Backfill

Backfill for the discharge line consisted of compacted and consolidated material. Consolidated backfill was placed to ½ foot above the pipe, and the remainder of the trench was filled with loose material to the original ground line. At road crossings and other areas subject to potential traffic, the entire trench was filled with compacted backfill.

Compacted backfill was placed using a hand-operated vibratory roller. Consolidated material was jetted into place and vibrated with a concrete vibrator.

Concrete Placement

Concrete was delivered to the site in transit mix trucks, placed, and consolidated. There were no unusual problems (Figure 357).

Discharge Line

The 24-inch, steel, discharge line was manufactured by the American Pipe and Construction Company. The pipe was placed in the trench with a large boom tractor. Joints were welded and the protective coating of coal-tar tape and primer for the joints was applied in the trench.

Other Construction

Paving of the access road, installation of fence, and construction of the electrical-mechanical control building were routine.

The pumps and motors were installed by the contractor under Specification No. 67-25. No unusual methods were required to install the equipment.

Controls, transformers, and other electrical equipment were prefabricated by various suppliers and installation was routine.

Figure 355. Preliminary Site Work

Figure 356. Discharge Line Trench

Figure 357. Forms and Reinforcing Steel—Pump Foundation

The following engineering drawings may be found in consecutive order immediately after this reference (Figure 358 through 366).

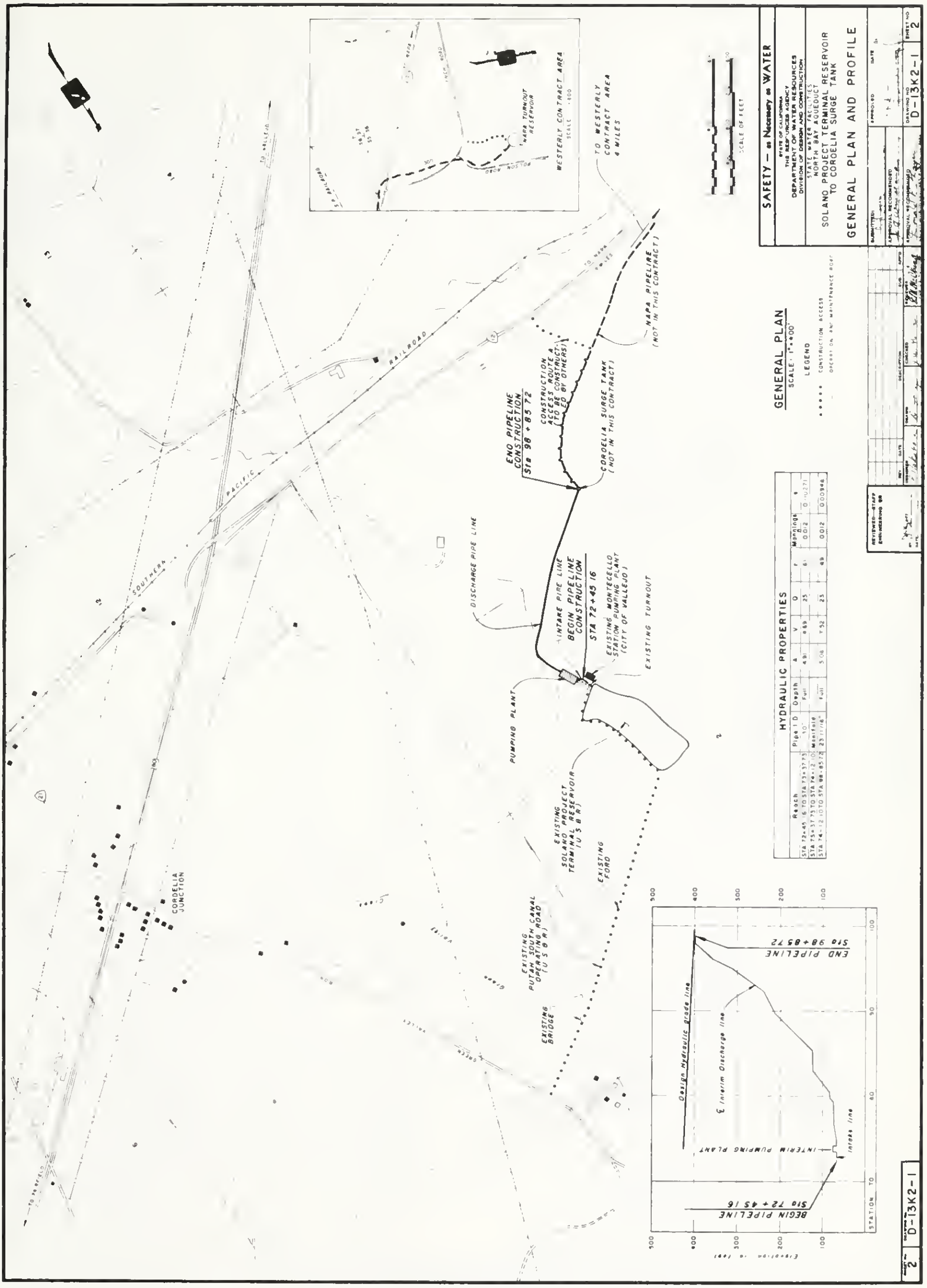

Figure 358. General Plan and Profile

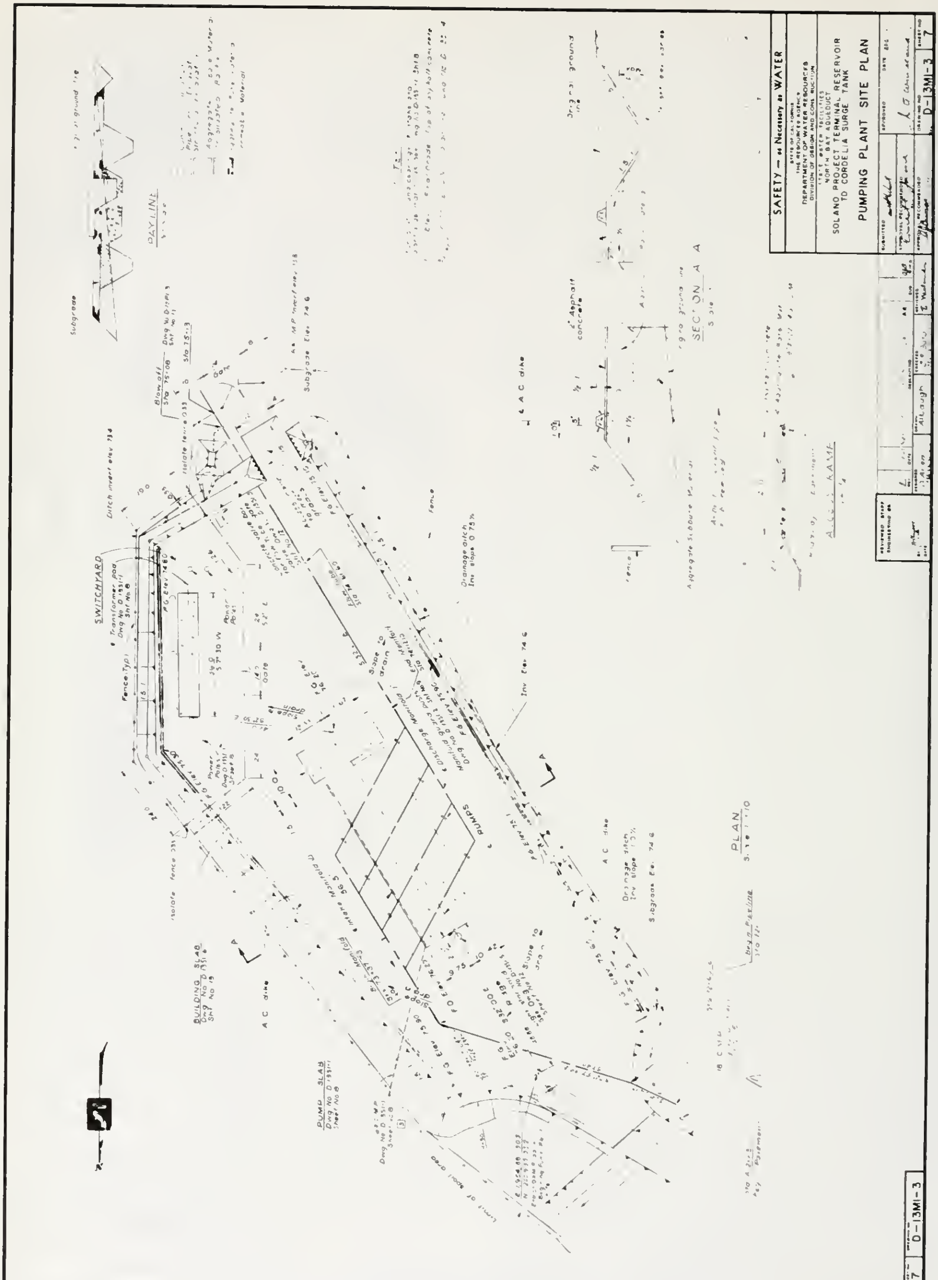

Figure 359. Site Plan

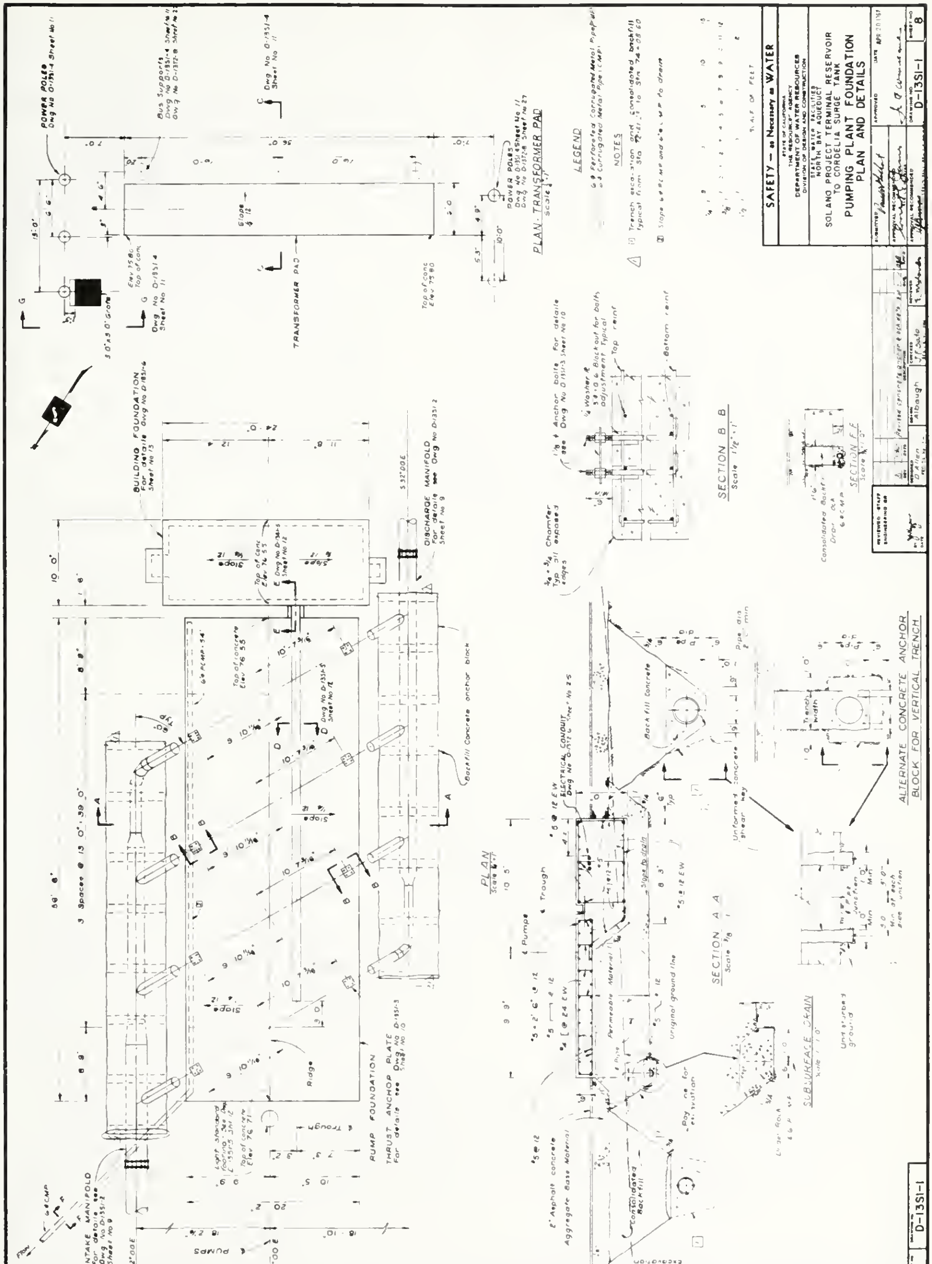

Figure 360. Foundation

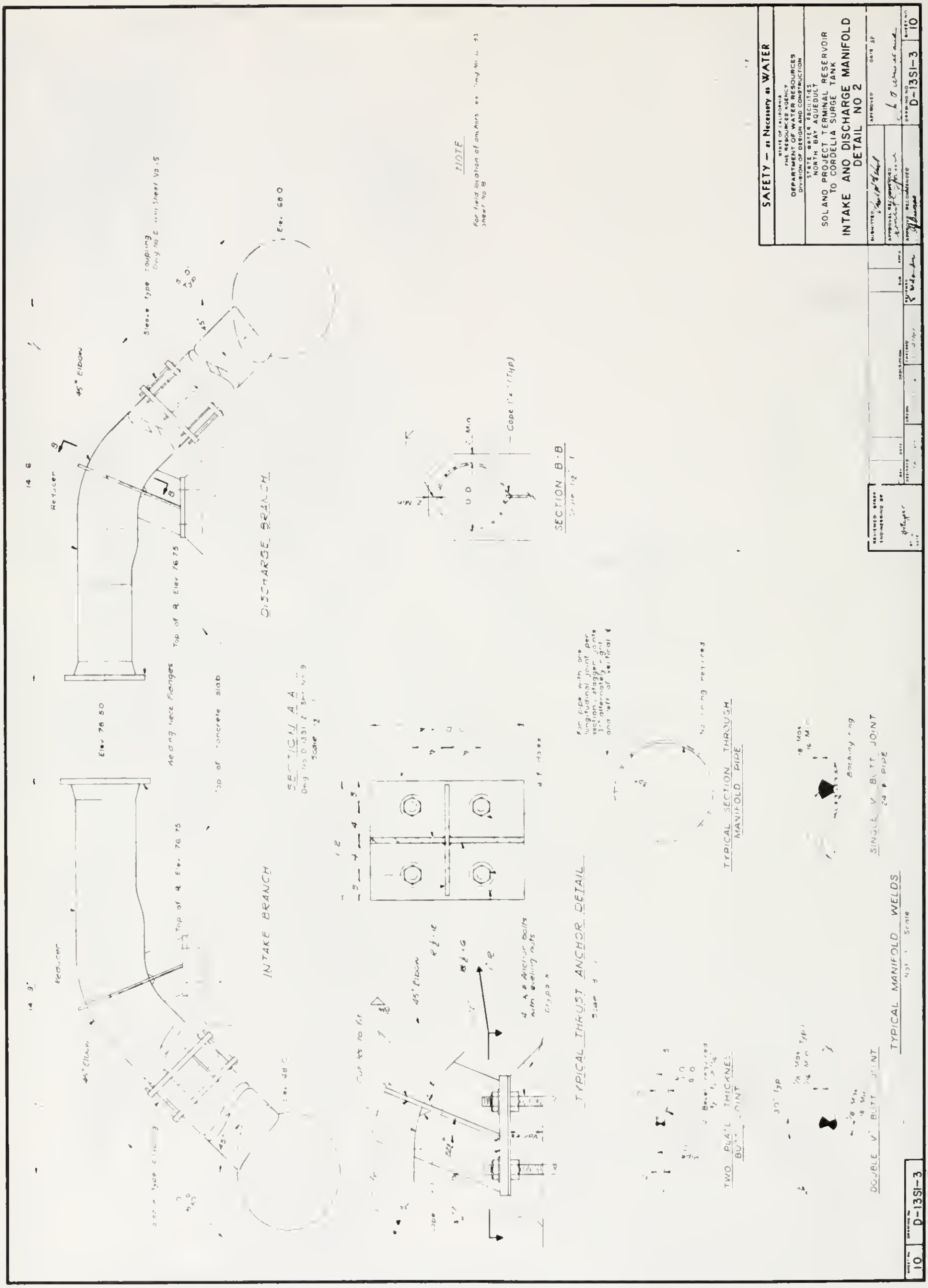

Figure 361. Manifold

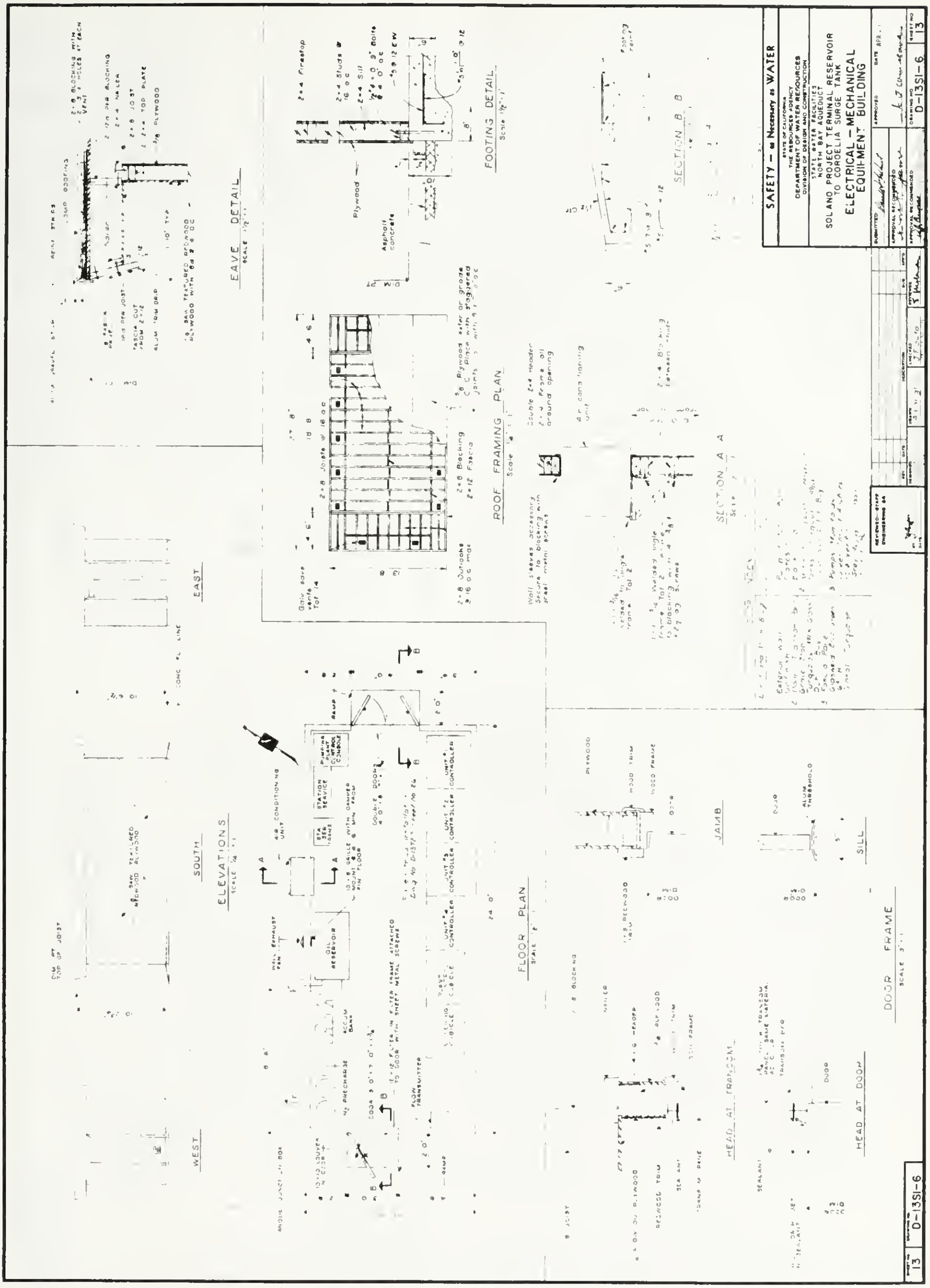

Figure 362. Equipment Building

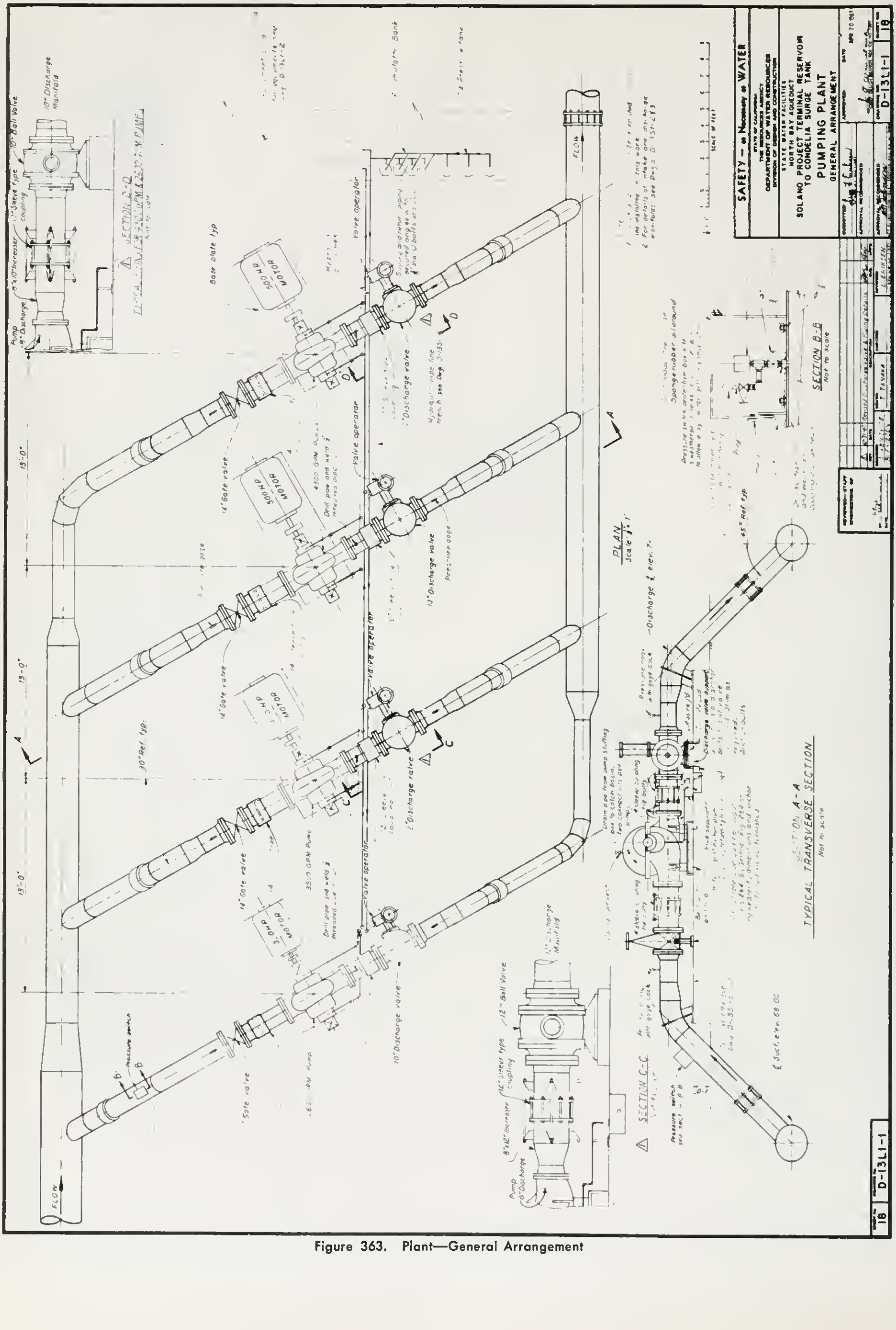

Figure 363. Plant—General Arrangement

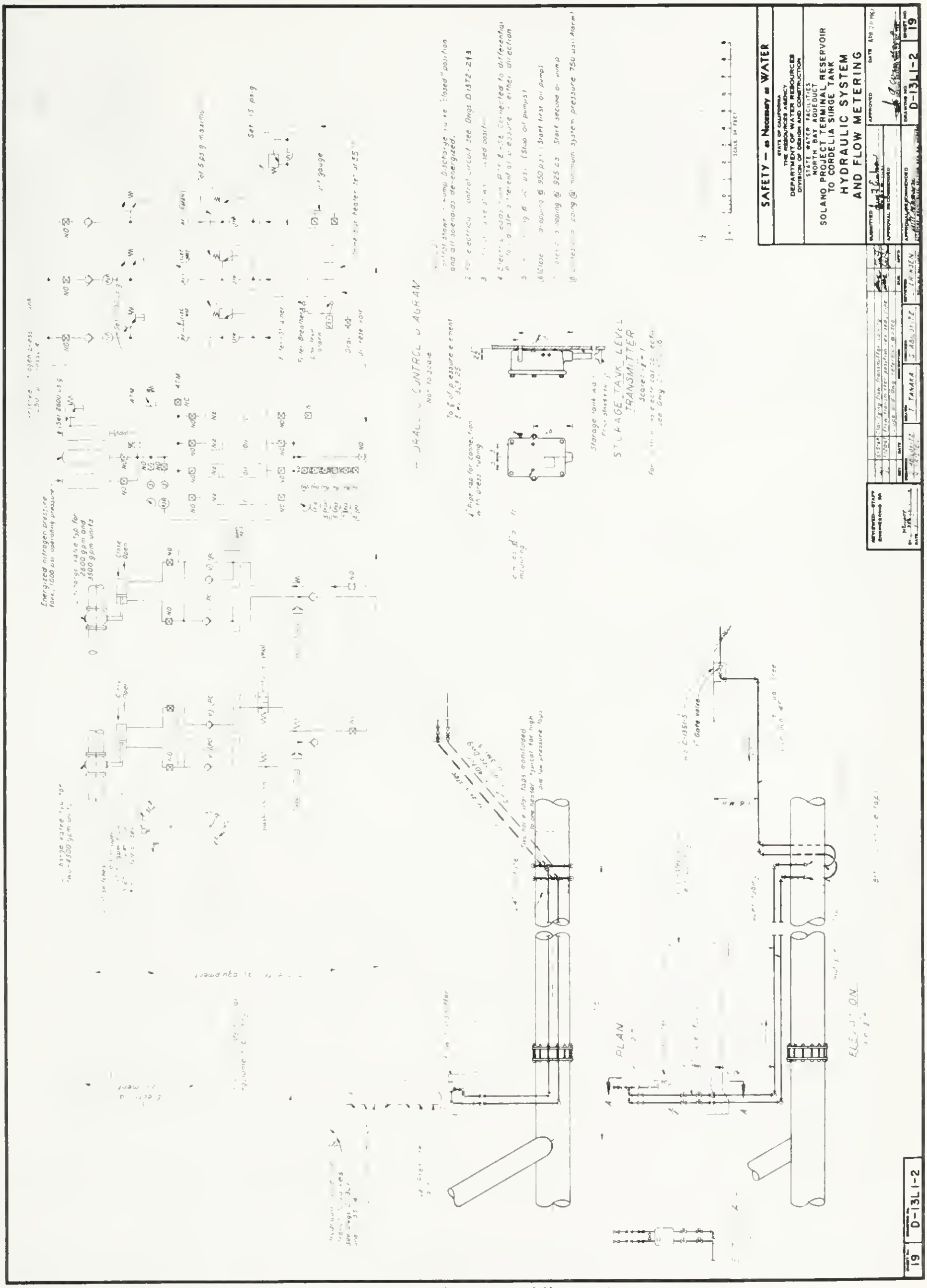

Figure 364. Hydraulic System and Flowmetering

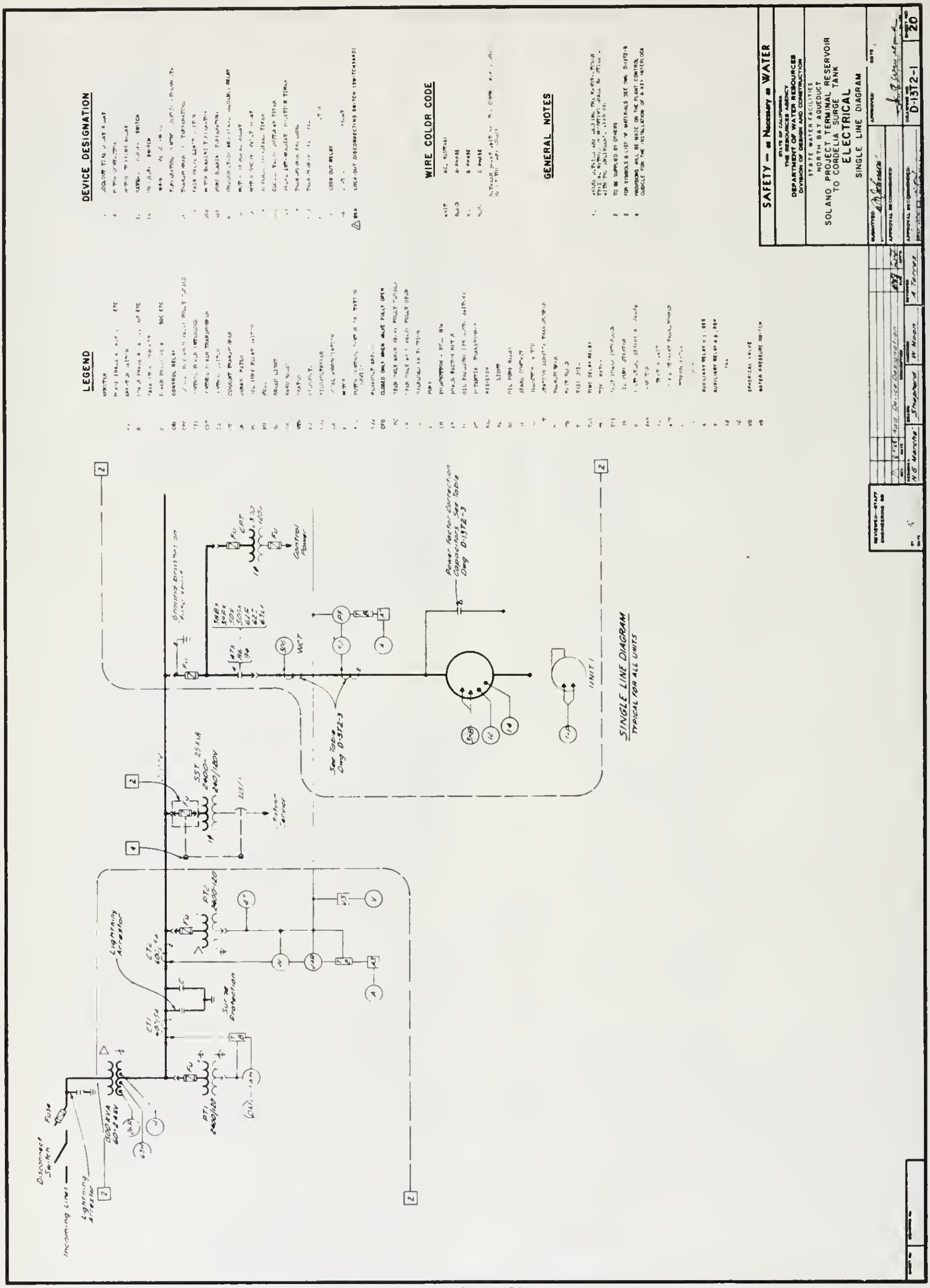

Figure 365. Single-Line Diagram

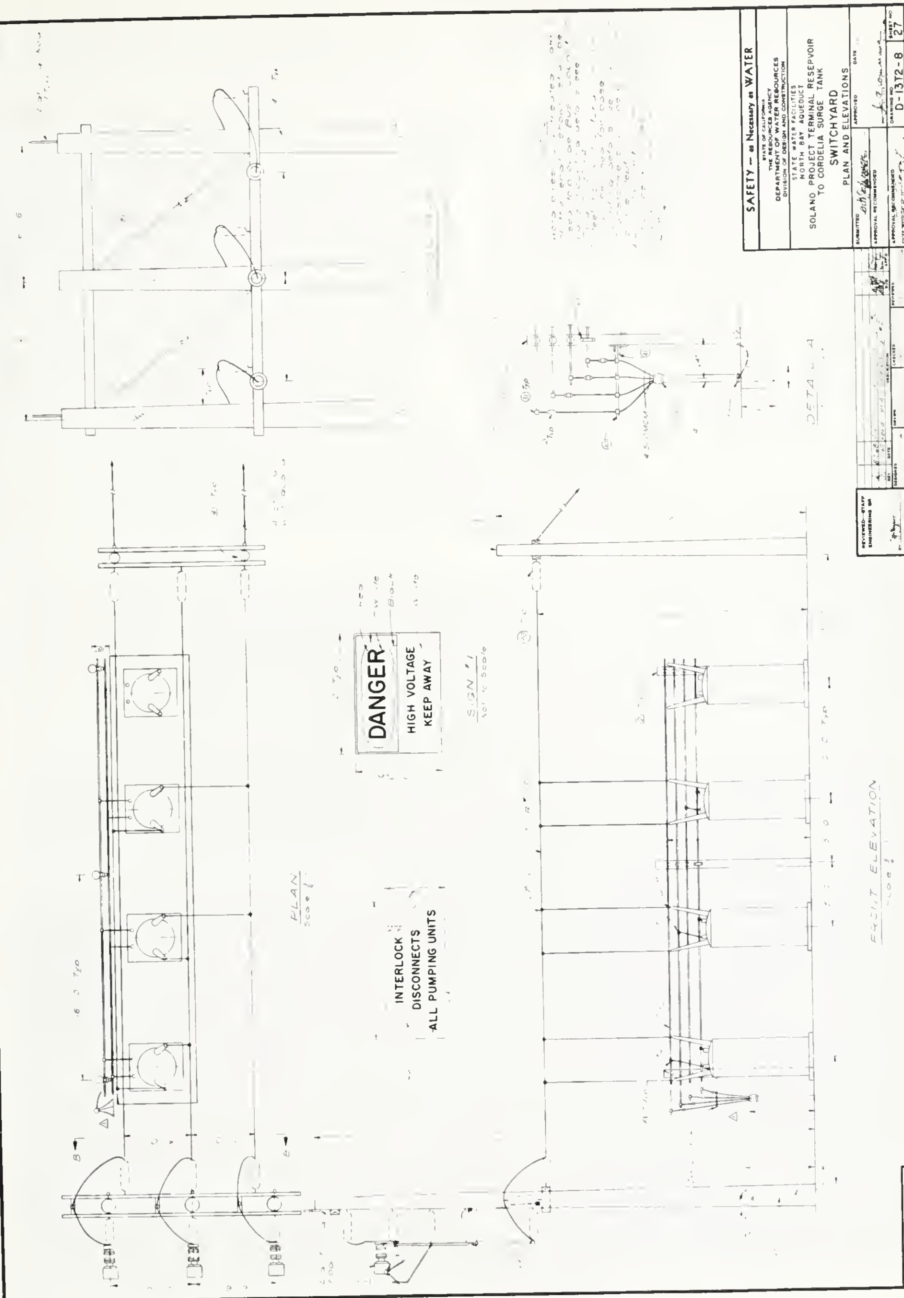

Figure 366. Switchyard

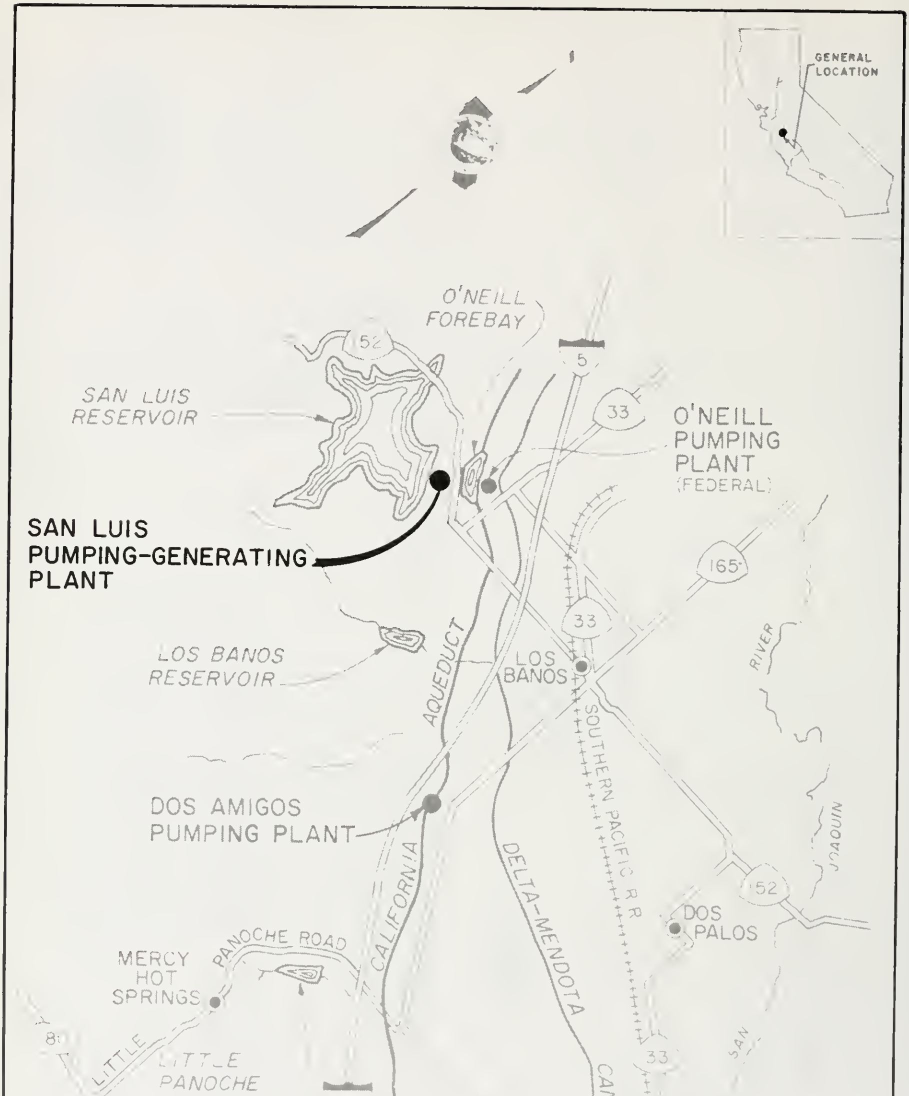

Figure 367. Location Map--San Luis Pumping-Generating Plant

CHAPTER VIII. SAN LUIS PUMPING-GENERATING PLANT

General

Introduction

This chapter contains only a brief description of the San Luis Pumping-Generating Plant. It was designed and constructed by the U.S. Bureau of Reclamation, and detailed information is available in its technical records of design and construction (see Bibliography).

The San Luis Joint-Use Facilities are the integrated facilities serving the U.S. Bureau of Reclamation Central Valley Project and the State Water Project. They extend from O'Neill Forebay to Kettleman City, about 106 miles. In this reach of the California Aqueduct (the San Luis Unit of the Central Valley Project), the Bureau of Reclamation has contracted for delivery of water to a service area of approximately 500,000 acres on the west side of the San Joaquin Valley, known as the San Luis Unit of the Central Valley Project (Figures 367 and 368). San Luis Unit was federally authorized by Act of Congress, PL 86-488, which became law on June 3, 1960 (74 Stat. 156).

The canal route for conveying water for the State Water Project to state service areas in the San Joaquin Valley and Southern California is through the federal San Luis service area. Both state and federal projects required development of the San Luis Dam site, west of Los Banos, for storage of surplus flows pumped from the Sacramento-San Joaquin Delta. Accordingly, the most logical and economical development for California and the United States was to integrate the storage, pumping, and conveyance facilities for coordinated operation into common facilities. The agreement of December 30, 1961, between the State and the United States, achieved those results.

The agreement provided that the Bureau of Reclamation would design and construct the San Luis Joint-Use Facilities and cost sharing would be 55% State and 45% United States. The State assumed responsibility for operation and maintenance according to pro-

Figure 368. San Luis Pumping-Generating Plant

portionate use of facilities. Lands and rights of way for San Luis and O'Neill Forebay dams and reservoirs were obtained by the State. Titles to property secured by the State were later transferred to the United States.

The federal authorization act did not contain construction funds. State funds from the Water Resources Development Bond Act were advanced in 1961 to the Bureau of Reclamation so that design could be expedited. The first federal appropriation came later.

The official San Luis Unit ground-breaking ceremonies were on August 18, 1962. The event was highlighted by the presence of President John F. Kennedy.

Location

San Luis Pumping-Generating Plant is located about 12 miles west of Los Banos adjacent to State Highway 152 and near the terminus of the North San Joaquin Division of the California Aqueduct. It is about 70 miles south of the Delta Pumping Plant.

The plant is situated at the base of the left abutment of San Luis Dam (Figure 368). The intake to the plant forms an arm of O'Neill Forebay.

Purpose

San Luis Pumping-Generating Plant pumps from O'Neill Forebay into San Luis Reservoir which stores water surplus to the needs of the Sacramento-San Joaquin Delta and in excess of requirements of service areas farther south. Water is released through the plant, in the generating mode, when service area demands are in excess of direct Delta diversions.

Water flows from the Delta to O'Neill Forebay at maximum rates of 10,000 and 4,200 cubic feet per second (cfs) from the State's California Aqueduct and the U. S. Bureau of Reclamation's Delta-Mendota Canal, respectively. O'Neill Forebay, San Luis Pumping-Generating Plant, Dos Amigos Pumping Plant, San Luis Dam and Reservoir, and 103 miles of San Luis Canal to the south comprise the main features of the San Luis Joint-Use Facilities with each agency's water being first comingled at O'Neill Forebay. Storage in San Luis Reservoir provides peak demand capabilities for both systems.

Description

San Luis Pumping-Generating Plant is an indoor-type plant (Figure 368). Its overall dimensions are 483 feet by 97 feet. Insofar as possible, pumping is off-peak and water releases are made during peak power demand periods. There are eight pumping-generating units. Because of the extreme head variations, from 99 to 327 feet, the pump-turbines operate at two speeds, 120 and 150 rpm. When operated in the pumping mode, the eight units have a combined capacity of 11,000 cfs with a dynamic head of 290 feet. When releasing water at 13,120 cfs, the plant is operated for power generation with a capacity of 424,000 kilowatts. The switchyard is located southeast of the plant.

There are four 17½-foot-diameter inlet-outlet tunnels, each serving two plant units. The tunnels are steel-lined for part of their 2,150-foot lengths. Butterfly valves are located in the plant adjacent to the anchor block encasing the steel bifurcation. Each tunnel has its own trashrack structure. The four trashrack structures rise as independent units about 310 feet above the foundation rock.

Representative drawings are included at the end of this chapter.

Architectural Design

The plant substructure is reinforced concrete. The superstructure is steel framing with brick enclosure walls. The lower part of the walls is reinforced brick masonry with exterior red and interior buff-colored brick. The upper walls are covered with insulated metal wall panels. This general scheme is used at the other plants designed by the Bureau of Reclamation for the San Luis Unit. The roof deck is steel with built-up roofing.

A glass-enclosed observation deck for visitors is located at the south end of the plant and 25 feet above the motor-generator floor. The visitors area includes an exhibit space.

Geology

The rock types in the general area of the plant site are conglomerates and interbedded shale and sandstone. Foundation for the main plant structure is in unweathered conglomerates near elevation 168 feet.

The inlet-outlet tunnels in this area penetrated both rock types. Geologic faulting intersecting the tunnel alignments influenced the method and sequence of tunnel construction. The Gonzaga fault, a zone about 20 feet thick, was the principal foundation defect.

Civil Features

The plant is built in monolithic structural bays accommodating eight motor-generator units and the service and control bay at the south end. The bays are separated by transverse expansion joints spaced at 93 feet. Longitudinal expansion joints separate the butterfly valve and control rooms from the rest of the plant structure.

The four inlet-outlet tunnels were driven from upstream and downstream headings simultaneously. Approximately 1,000 feet of the upstream end of each tunnel is lined with concrete, 2½ feet thick. The lining in sections with low cover at the Gonzaga fault near the west portal is 3½ feet thick. The tunnels are steel-lined for 1,175 feet near the downstream portals because of the shallow tunnel cover and the greater internal water pressures.

Separate trashrack towers rise 284 feet from a massive concrete footing excavated more than 60 feet into unweathered rock. The rock is sandstone interbedded with thin shale. About 2,300,000 cubic yards were excavated in preparation of the tower foundations. Bulkhead gates for dewatering of the tunnels are located in the towers. A six-span vehicular bridge provides access to the towers from the dam crest.

Mechanical Features

The mechanical installation at the San Luis plant includes eight pump-turbines; eight 156-inch-turbine shutoff, butterfly valves; one 350-ton, electric, overhead crane; and station service auxiliary equipment. No provisions have been made for load regulation.

Pump-Turbine Rating

Manufacturer: Hitachi Limited
Type: Vertical, Francis, with fixed stay vanes

	Turbine Mode	*Pump Mode*
Horsepower:	35,000	—
Head:	197 feet	290 feet
Speed:	120 rpm	150 rpm
Discharge:	—	1,375 cfs

Electrical Features

The electrical equipment and systems for the San Luis plant include high-voltage switchyard, transformers, motor-generators, switchgear, auxiliary plant equipment, and protective devices. The motor-generators have two speeds for each mode of operation. They were manufactured by General Electric Company and have the following characteristics:

Generator Rating
53,000 kVA at 150 rpm
34,000 kVA at 120 rpm
13.8 kV, 3 phase, 100%power factor.

Motor Rating
13.2 kV, 3 phase
63,000 hp at 150 rpm
95% power factor
34,000 hp at 120 rpm
100% power factor

Construction

Construction of San Luis Pumping-Generating Plant was included in the construction contract for San Luis Dam and O'Neill Forebay Dam. The contract was awarded to the joint venture of Morrison-Knudsen Company, Inc., Utah Construction and Mining, and Brown and Root, Inc., for $85,926,608 on January 8, 1963.

The work commenced with excavation for the trashrack towers on February 18, 1963 and was followed in a few days by foundation preparation for the plant. All contract work was completed on August 4, 1967.

A total of 2,138,000 cubic yards of material, mostly conglomerate, was excavated from the San Luis Pumping-Generating Plant and switchyard sites. Blasting was necessary below 20 feet of depth. Excavation was completed in December 1963. The first concrete was placed in the plant foundation on December 12, 1963.

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 369 through 372.)

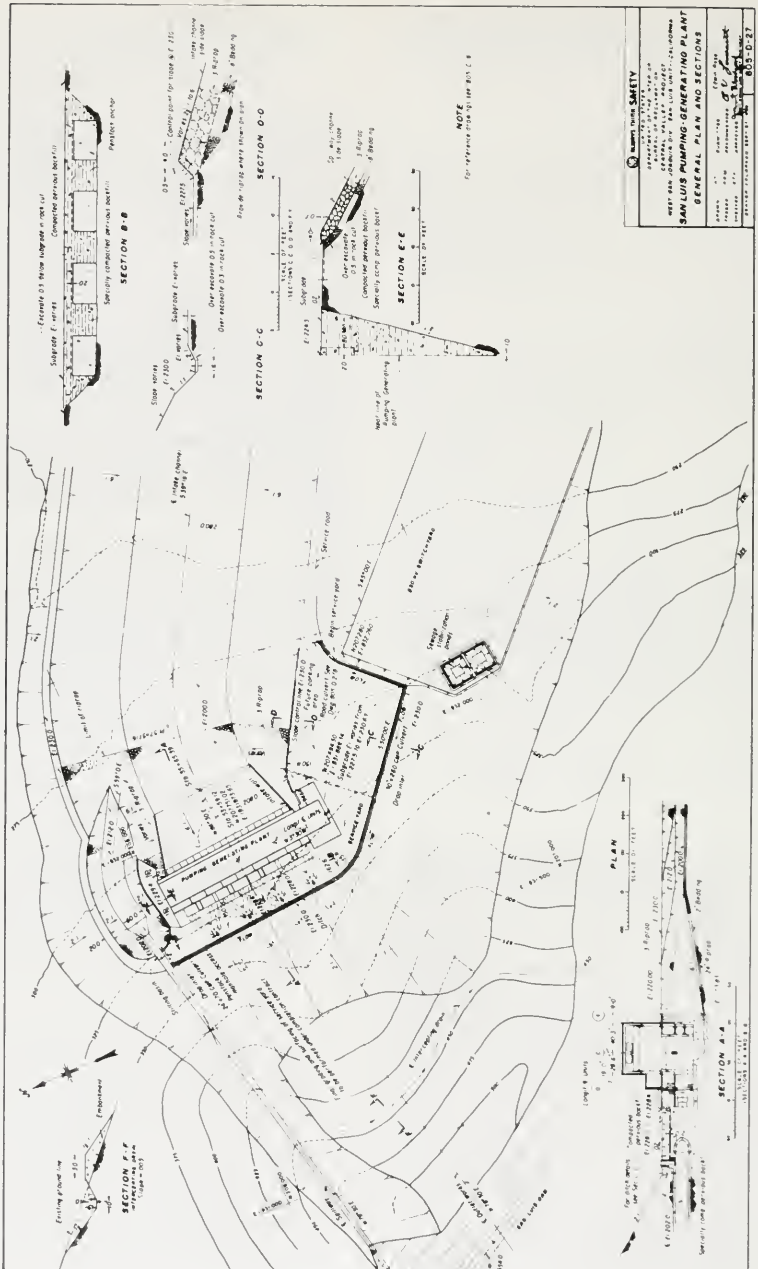

Figure 369. General Plan and Sections

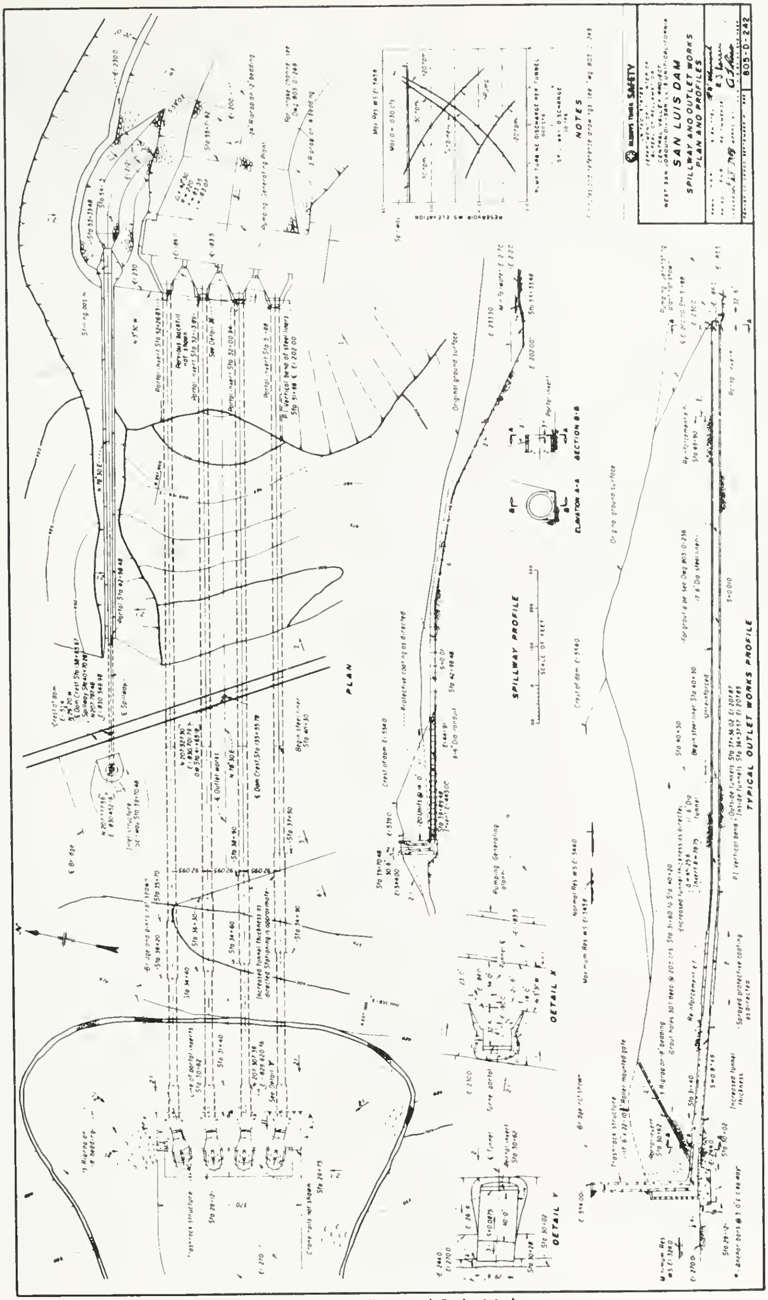

Figure 370. Spillway and Outlet Works

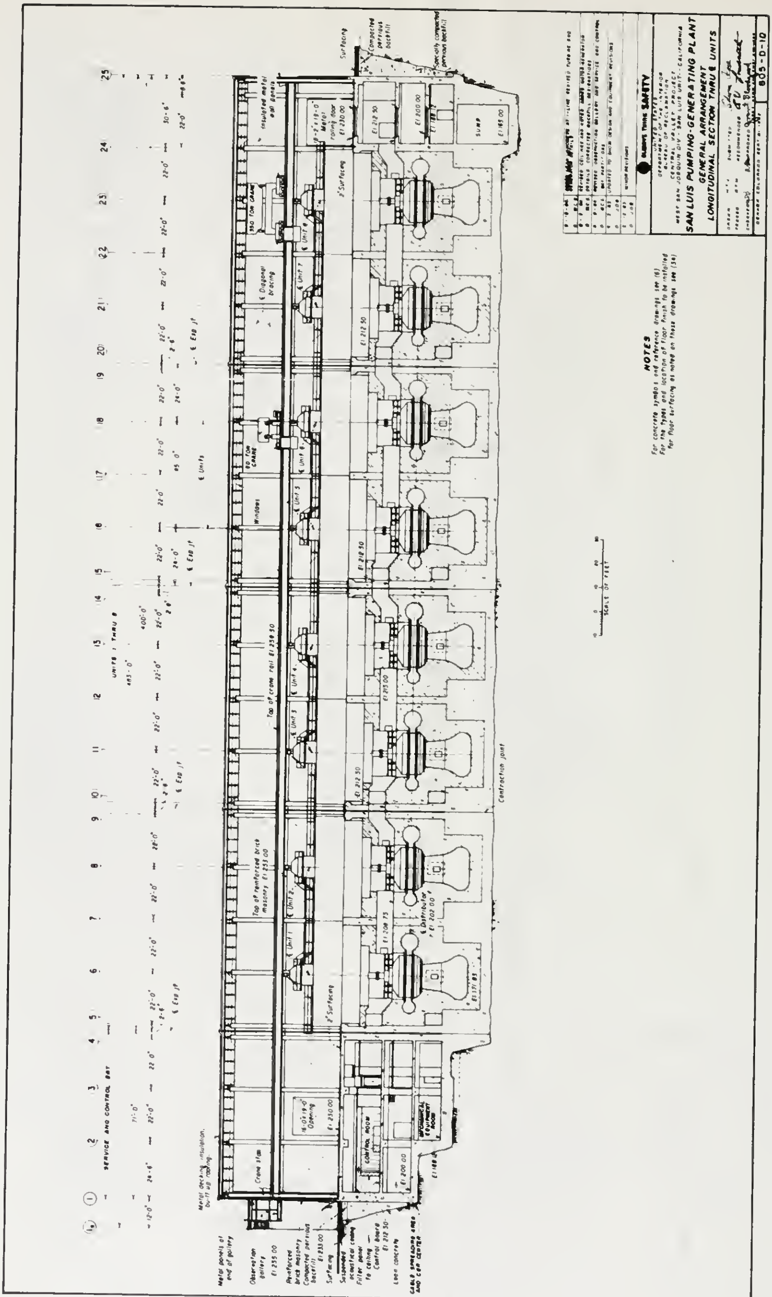

Figure 371. Longitudinal Section

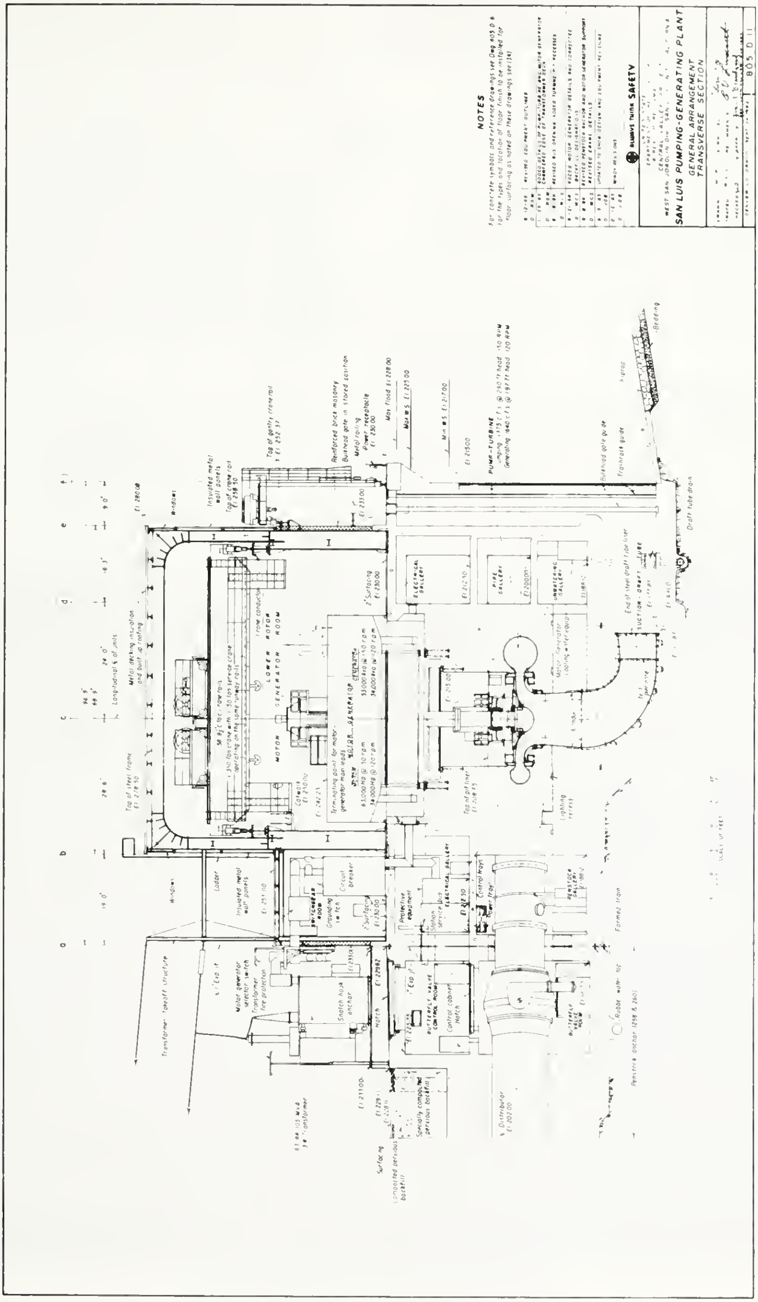

Figure 372. Transverse Section

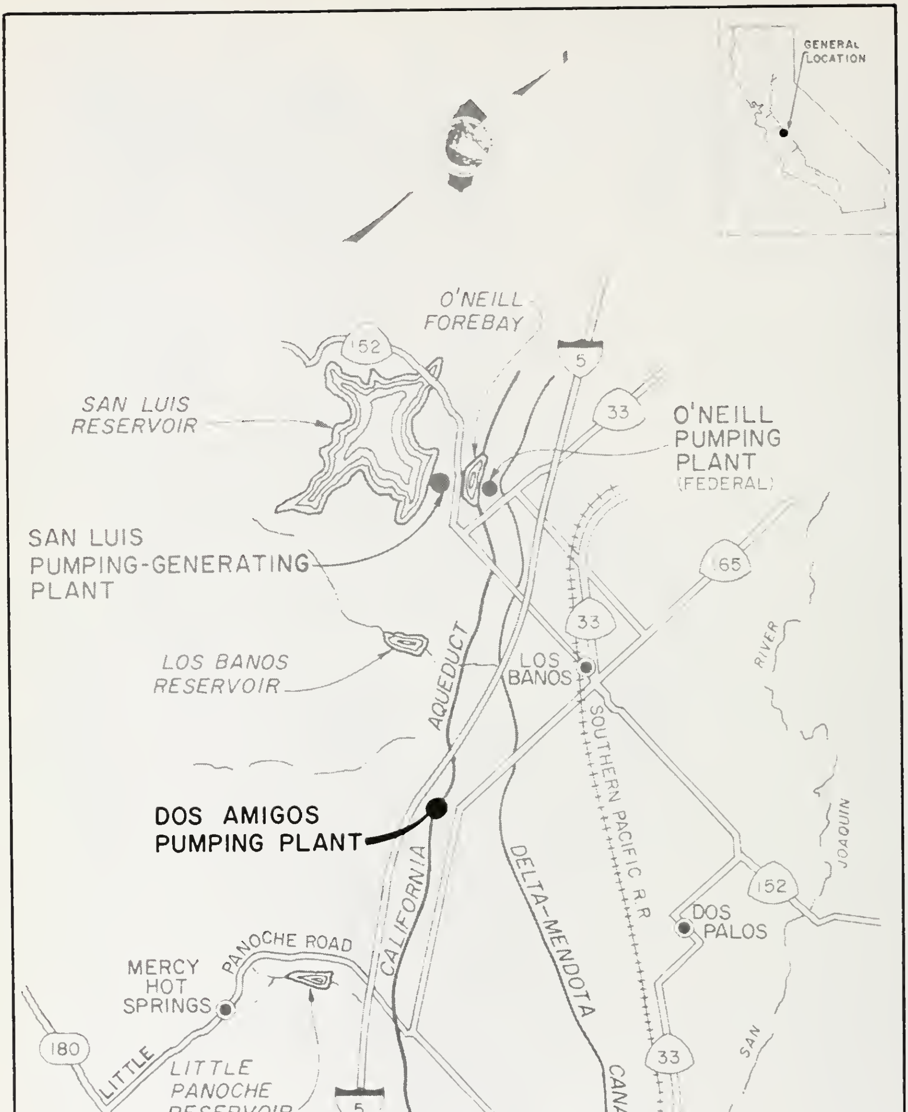

Figure 373. Location Map—Dos Amigos Pumping Plant

CHAPTER IX. DOS AMIGOS PUMPING PLANT

General

Introduction

This chapter contains only a brief description of Dos Amigos Pumping Plant. It was designed and constructed by the U. S. Bureau of Reclamation as a part of the San Luis Joint-Use Facilities. A general discussion of the Joint-Use Facilities is contained in Chapter VIII of this volume, and detailed information is available in the U. S. Bureau of Reclamation's technical records of design and construction (see Bibliography).

Location

Dos Amigos Pumping Plant (Figure 373) is located on the California Aqueduct, about 10 miles south of Los Banos and 18 miles southeast of San Luis Dam in Merced County. The plant was originally called Mile 18 Pumping Plant; however, on October 28, 1965, the name officially was changed to Dos Amigos Pumping Plant.

Purpose

Dos Amigos Pumping Plant lifts water 113 feet from the California Aqueduct as it flows south from O'Neill Forebay. The plant provides service to the Federal San Luis Unit of the Central Valley Project and beyond to the State Water Project in the San Joaquin Valley and Southern California.

Description

This plant has an indoor-type superstructure. The structure has an overall length of 388 feet, width of 126 feet, and height of 127 feet measured from its lowest foundation to the roof. Pumping facilities include an intake transition, six discharge lines, outlet transition structure, and switchyard (Figure 374).

The plant houses six pumps, each rated at 2,200

Figure 374. Aerial View—Dos Amigos Pumping Plant

cubic feet per second (cfs). Three of the pumps are centrifugal, and the other three are Deriaz units that can be used to vary the discharges from 1,200 to 2,200 cfs. Total plant pumping capacity is 13,200 cubic feet per second.

The main structure consists of three independent plant monoliths. The monoliths are separated by expansion joints, and these joints are protected from leakage by rubber waterstops.

Representative drawings are included at the end of this chapter.

Architectural Design

The plant substructure is reinforced concrete. The superstructure is structural steel framing with brick enclosure walls. Two kinds of brick construction were used. The main superstructure is reinforced brick masonry with exterior red and interior buff-colored brick, and the switchgear rooms and visitors gallery exterior walls are faced with red brick veneer. The brick masonry reinforcement is welded to steel columns resulting in an unbroken exterior. There is a 1-inch expansion joint through the brick continuous with the plant monoliths. The roof deck is steel with built-up roofing.

There is a glass-enclosed viewing area for visitors at the west end of the plant, two floors above the main motor floor. The visitors area includes an exhibit room.

The architectural motif for Dos Amigos Pumping Plant was selected by the U. S. Bureau of Reclamation and, in many aspects, differs from that used for plants designed by the Department of Water Resources.

Geology

Site Geology

The California Aqueduct, at Dos Amigos Pumping Plant, is on deep valley fill adjacent to the Laguna Seca Hills. Dos Amigos is located in the northeast slope of an alluvial fan composed of mud flows from erosion which has caused many small gullies in the hills. The plant is about 1,500 feet from the mouth of a ravine at the apex of the fan. The mud flows, comprising the fan, have resulted from brief but heavy rains. At the plant site, these deposits are about 130 feet thick and they overlie a 43-foot-thick formation known as Corcoran Clay. The Corcoran Clay, in turn, overlies a gravelly material known as Tulare formation.

Ground Water

Ground water was of inferior quality, and its disposal during dewatering for the excavation was by evaporation and percolation into ponds.

Instrumentation

Prior to start of construction, 12 rebound settlement points were installed in the plant foundation to measure rebound during excavation and settlements during and after plant construction. They were placed at the following intervals: 2 feet below final excavation grade, at the top of the Corcoran Clay, at the top of the Tulare formation, and at mid-depth of the Corcoran formation.

Nine foundation-type piezometers were intalled in a similar arrangement at the rebound settlement points. The piezometer tubes terminate inside the plant at three display panels.

Civil Features

Site Development

Total excavation required for the plant and discharge lines was 895,000 cubic yards. Because of the expected foundation rebound, a plug of unexcavated material was left in the plant inlet transition until concrete placements were completed to the elevation of the service yard. After leveling, the plant area was excavated uniformly to avoid differentials in excess of 20 feet. Excavation to final plant grade was adjusted to allow for rebound. The maximum compensation for the effect of rebound, before concrete placement, was 0.4 foot of overexcavation.

Plant Structure

The gross dimension of the superstructure for each pump unit is 68 feet by 47 feet, width and center to center, respectively. The service bay located at the east end of the plant is 68 feet wide and 73.5 feet long and has four floors. In addition, there is a small service bay at the west end with five floor levels, and the plant sump is 71 feet below the main floor.

Concrete placements were scheduled so as to provide uniformity of loading in the unit bays below the grade of the dewatering gallery floor. All foundation placements were made first. Thereafter, no placement differential greater than two lifts, or 23 feet, was allowed. The first concrete placement was made on February 24, 1964.

Plant expansion joints contain double 9-inch waterstops and formed drains. The drains relieve any water passing the first waterstop.

Concrete quantities were:

Foundation	14,881 cubic yards
Substructure	42,431 cubic yards
Intermediate	11,240 cubic yards
Superstructure	799 cubic yards

The pumping plant structure, which required 1,700,000 pounds of structural steel, was completed on December 6, 1965. Field connections were made with bolts. Framing of the east end was delayed to install the 200-ton bridge crane.

Pump Discharge Lines

There are six 18-foot discharge lines. At the plant exit, each line is a 63-foot-long, ½-inch-thick, unencased, steel pipe 12 feet - 3 inches in diameter. The pipe passes through a vault and enlarges to 18 feet in a concrete-encased section 88 feet long. The first 30 feet of the lines are on a 2:1 slope and consist of concrete and steel lines and the remainder are reinforced concrete.

The discharge lines connect to the encased steel pipe of the siphon breaker approximately 77 feet from its crest. Downstream of the crest is a 36-foot-long transition to an 18-foot-square conduit. This is followed by another transition to a rectangular opening at the headwall, 18 feet wide by 24.4 feet high. The discharge lines are backfilled and completely covered with compacted material. There is a 62-foot by 22-foot siphon breaker control house with brick masonry typical of the pumping plant structure.

The concrete required for construction of the discharge lines was as follows:

Outlet transition	1,751 cubic yards
Monolithic concrete pipe	14,316 cubic yards
Line anchors	7,100 cubic yards
Siphon breaker encasement	4,524 cubic yards

Mechanical Features

The mechanical installation at Dos Amigos Pumping Plant includes six pumps, one 200-ton crane, siphon breaker, and station service auxiliary equipment. There are no pump discharge valves.

Pump Rating

Manufacturer:	English Electric Corp.
Type: (Pumps Nos. 1, 3, and 5)	Vertical, variable pitch, variable flow, Deriaz
(Pumps Nos. 2, 4, and 6)	Vertical, centrifugal
Discharge: (Pumps Nos. 1, 3, and 5)	200–2,200 cfs
(Pumps Nos. 2, 4, and 6)	2,200 cfs
Head:	125 feet
Speed:	120 rpm

The specifications for the Deriaz units anticipated a discharge range of 200 cfs to 2,200 cfs. However, field tests indicated vibration problems at the lower capacities. Reevaluation of pumping requirements showed that the lower capacities were not required, allowing the pumps to operate in a vibration-free range between 1,200 and 2,200 cfs.

Electrical Features

The electrical installation for Dos Amigos Pumping Plant includes the switchyard, motors, switchgear, auxiliary equipment, and protective equipment. Motors were manufactured by ASEA Electric Company and are rated a 40,000 horsepower, 3 phase, 13.2 kV, 120 rpm, and 95% power factor.

Construction

The contract for construction of Dos Amigos Pumping Plant was bid at $8,972,555 and awarded on August 30, 1963, to the joint venture firm of Stolte, Inc., M. M. Sundt Construction Company, and Santa Fe Engineering. The contract was accepted as complete on July 8, 1966. Installation of equipment was performed under a separate contract.

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 375 through 378).

Figure Number	
375	Location Plan
376	Longitudinal Section
377	Transverse Section
378	Monolithic Concrete Pipe—General Plan and Profile

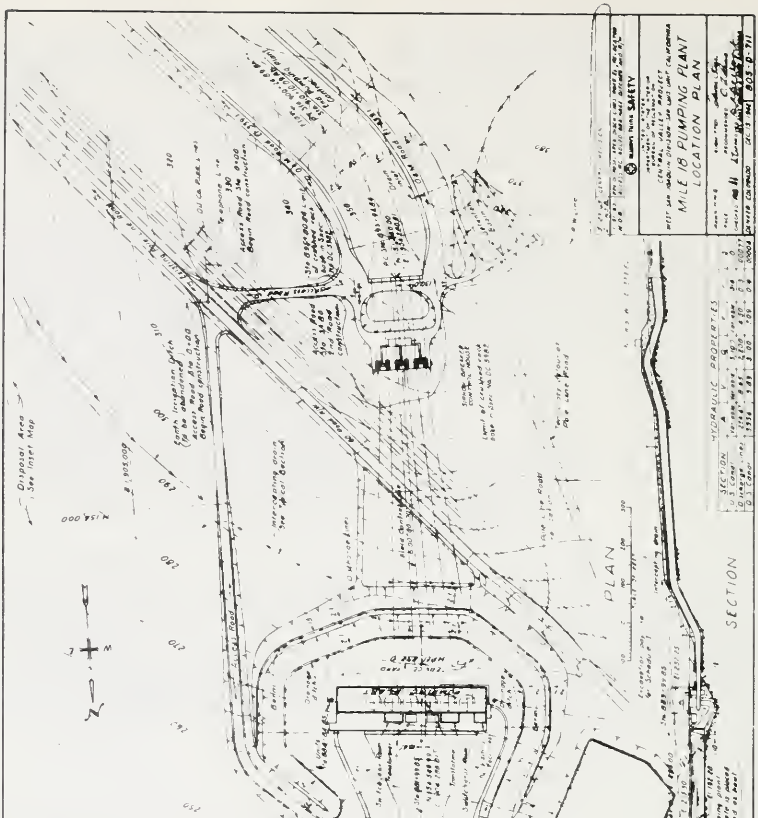

Figure 375. Location Plan

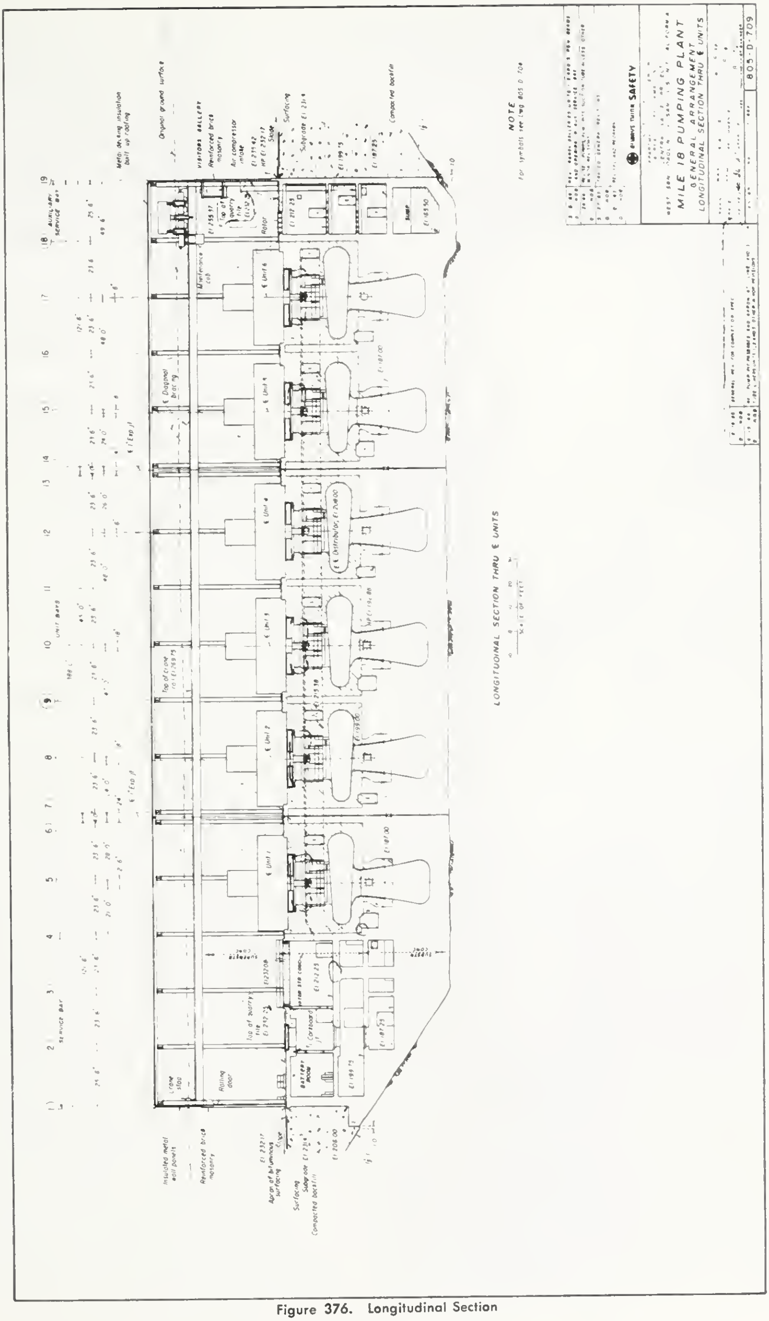

Figure 376. Longitudinal Section

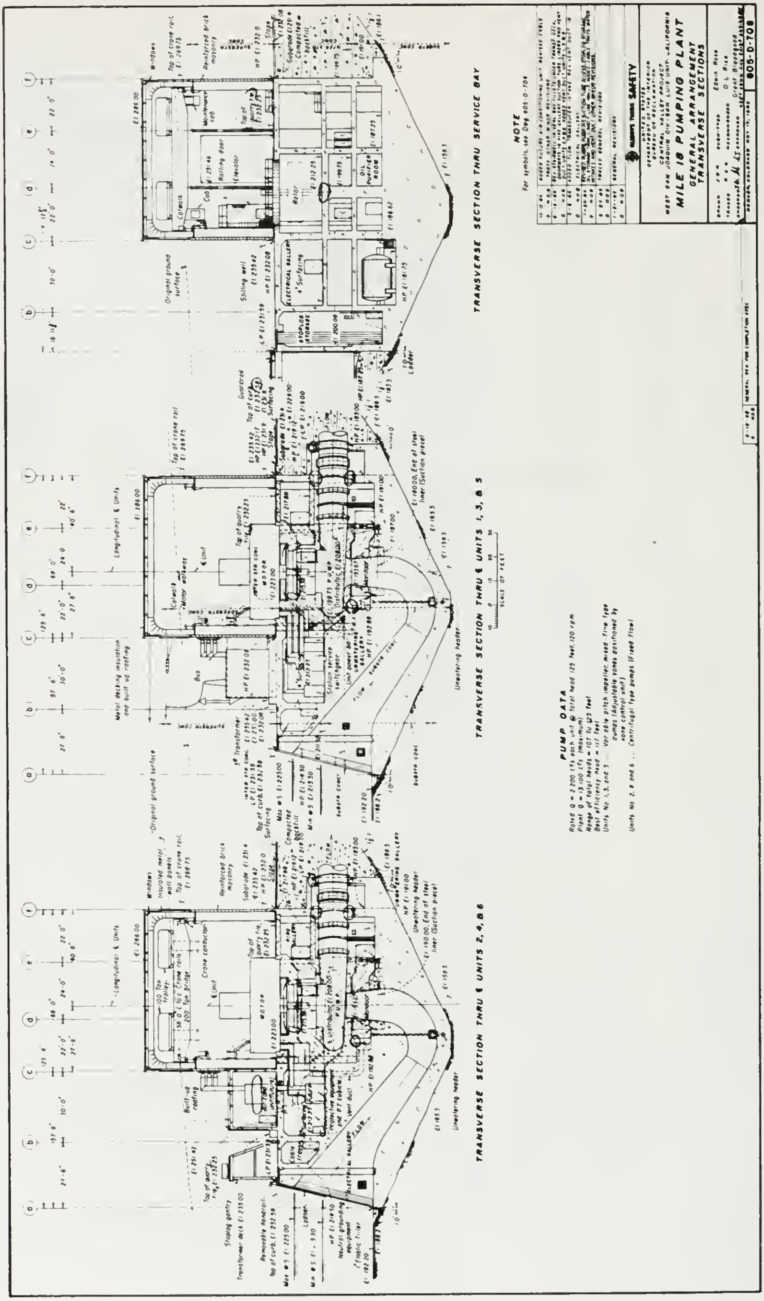

Figure 377. Transverse Section

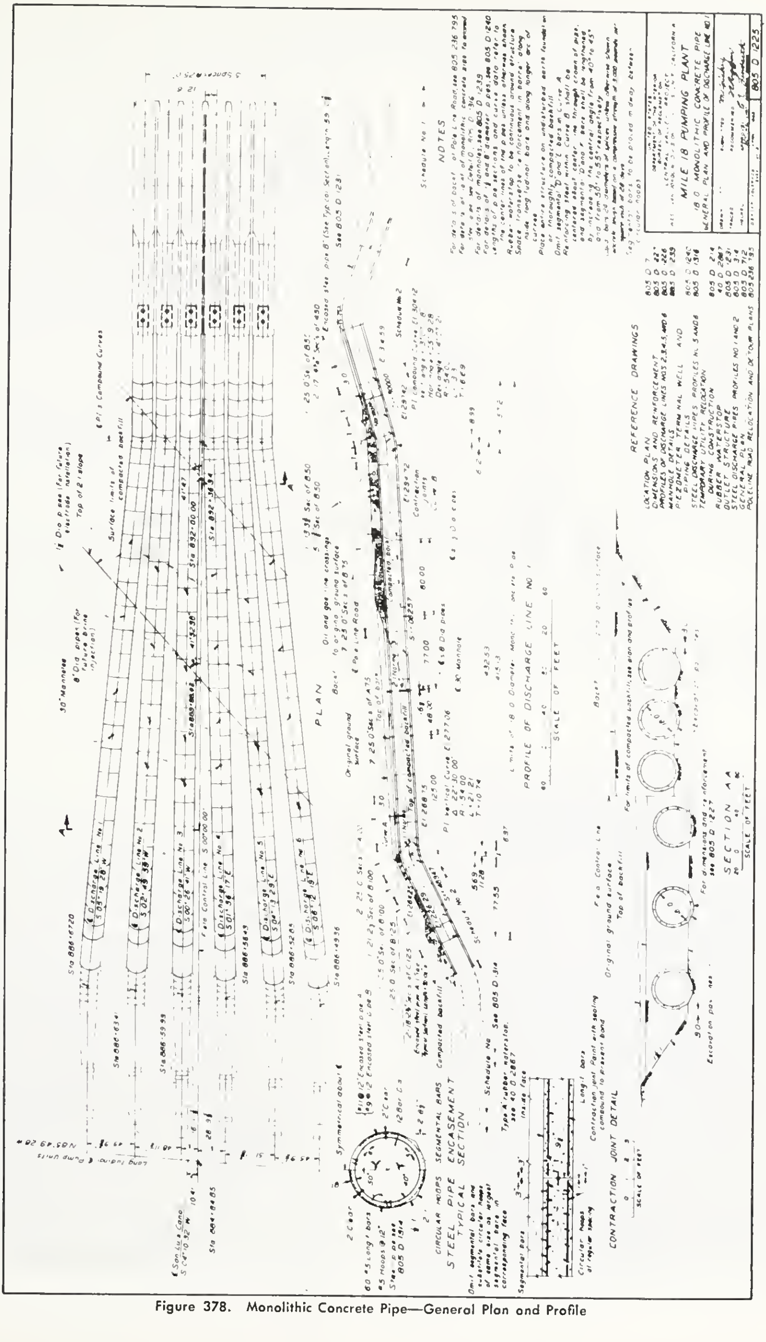

Figure 378. Monolithic Concrete Pipe—General Plan and Profile

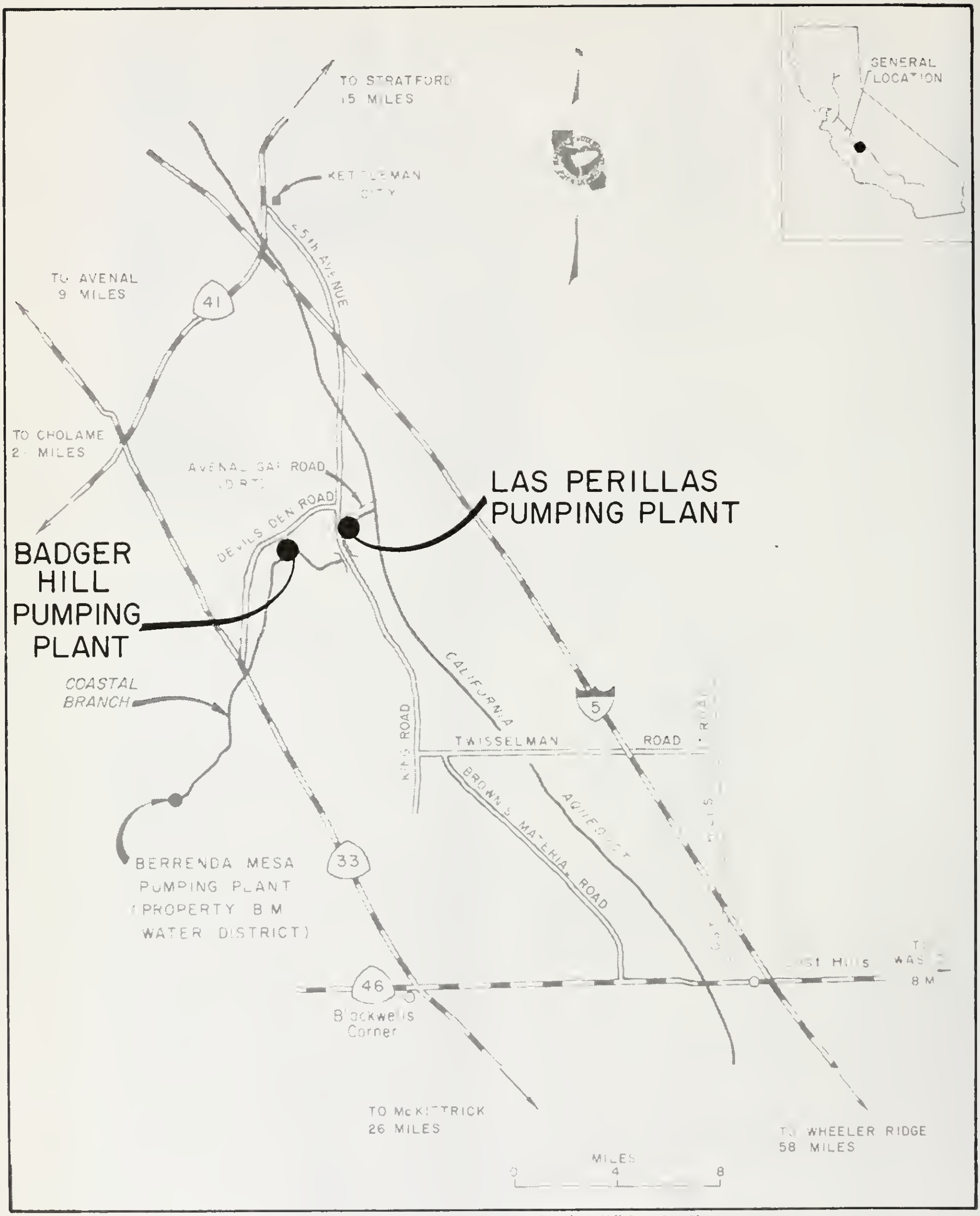

Figure 379. Location Map—Las Perillas and Badger Hill Pumping Plants

CHAPTER X. LAS PERILLAS AND BADGER HILL PUMPING PLANTS

General

Location

Las Perillas and Badger Hill Pumping Plants are located on the Coastal Branch, which diverts water from the California Aqueduct approximately 12 miles south of Kettleman City. Las Perillas Pumping Plant is approximately 1 mile from the California Aqueduct, and Badger Hill Pumping Plant is approximately 3 miles downstream from Las Perillas (Figures 379 and 380).

Purpose

These plants lift water from the California Aqueduct for delivery through the first 15 miles of the Coastal Branch. Construction of the remainder of the Coastal Branch has been deferred until about 1983.

Description

The two plants are similar in appearance and construction, the most noticeable difference being a visitors building incorporated into the Las Perillas Pumping Plant superstructure. Pump forebays are concrete-lined enlargements of the canal, and discharge lines are buried pipes, steel at Las Perillas and steel and concrete at Badger Hill.

Each plant contains six pumping units: three horizontal centrifugal pumps with a capacity of 38 cubic feet per second (cfs) each and three vertical centrifugal pumps at 112 cfs each. Plant capacity is 450 cfs at a head of 61 feet at Las Perillas and 163 feet at Badger Hill (Figure 381).

Representative drawings are included at the end of this chapter.

Geology

Areal Geology

Kettleman Hills anticline on the west side of the San Joaquin Valley dominates the area. This is a large structure consisting of three domes known as North, Middle, and South Domes. The Aqueduct crosses the anticline along the southern margin of Avenal Gap, a valley in the structural low between Middle and South Domes. Tulare formation and San Joaquin formation crop out along the margins of Avenal Gap, and Recent alluvium fills the valley floor.

Site Geology—Las Perillas

Las Perillas Pumping Plant is on the east dipping limb of South Dome of the Kettleman Hills anticline. Plant excavation was in alluvium and the San Joaquin

Figure 380. Las Perillas (left) and Badger Hill (right) Pumping Plants

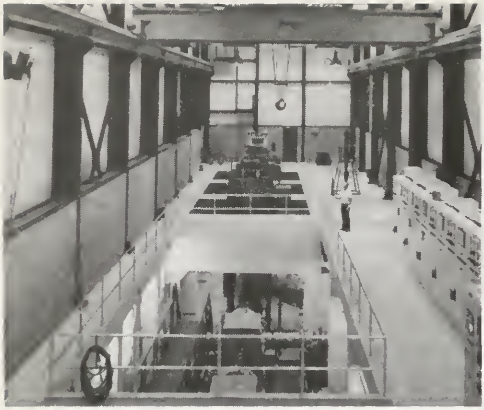

Figure 381. Interior View—Las Perillas

formation. The alluvium consists of silty sand and poorly graded sand with lenses of gravel, interbedded silty sands, silts, and medium to highly plastic clays with silt lenses. The San Joaquin formation is a silty sand, clay, siltstone, and claystone that forms the foundation for the Pumping Plant and discharge lines.

Bedding plane shears that reflect slippage during the folding of the Kettleman Hills anticline were mapped in the excavation. Block slippage occurred along some of the shear planes as a result of construction, and overbreak occurred where excavation walls intersected shear zones.

Ground water was encountered in the alluvial sand and gravel and necessitated dewatering by pumping from sumps in the plant excavation.

Site Geology—Badger Hill

Badger Hill Pumping Plant is on the west dipping limb of the South Dome of the Kettleman Hills anticline. Plant excavation was in alluvium and the underlying Tulare formation. The alluvium consists of poorly graded lenticular sand and gravel; a bluish-gray, fine-grained, silty sand and clayey sand; and a mixture of interbedded clays and clayey sands. These relatively flat-lying alluvial deposits rest unconformably upon the Tulare formation.

The plant foundation is the Tulare formation, consisting of silty sand, poorly graded sand, and consolidated clays. One bedding plane shear was exposed between a silty sand bed and an overlying clay bed in the southeast wall of the drainage sump excavation. Ground water control was attained by a well point system and pumps within the excavation.

Geologic Exploration

Exploration at the Las Perillas site consisted of 8 rotary drill holes and 5 bucket auger holes. At the Badger Hill site, 12 rotary drill holes and 7 bucket auger holes were drilled. Geologic mapping and inspection took place as the excavation progressed.

Instrumentation

A tiltmeter was installed on the north side of the Aqueduct near the Badger Hill Pumping Plant site shortly before excavation began. Tilt was recorded as excavation for the plant progressed, but no tectonic or regional tilting likely to affect the operation of the facility was discerned.

Seismicity

No faults are known beneath or near the two plants. The sites, however, are located in a moderate to high seismic area. The active San Andreas fault is about 22 miles southwest of Las Perillas and 20 miles southwest of Badger Hill.

Civil Features

Preliminary Studies

Preliminary studies were made to determine: (1) if one or two plants would be required, (2) the location of the plant or plants, and (3) the configuration and size of the plants.

The studies showed that there was little cost difference between the one- and two-lift schemes. However, the single-lift scheme involved deep canal excavations for long distances and a large, deep, plant bowl excavation. In consideration of potential slides and ground water problems, the single-lift scheme was abandoned in favor of the two-lift scheme.

The plant sites were selected on the basis of foundation conditions and economics of canal excavation and pipeline construction.

Site Development

The major features of site development for the plants included the plant bowl, access roads, and drainage control.

The plant bowl excavations were sized to contain the plant, a small switchyard, a drainage ditch, and ample room to move heavy maintenance equipment around the plant. At Badger Hill, it was necessary to construct a dike to divert floodwaters from the north side of the bowl excavation.

Separate roads provide access to the Pumping Plants from nearby county roads. The Las Perillas access road is approximately ½ of a mile long while the Badger Hill road is ⅝ of a mile long.

Plant Structures

The two plant structures are almost identical, except the Las Perillas plant is 16 feet - 8 inches longer than the Badger Hill plant. The extra length provides space for a water treatment system whereas none was required at Badger Hill. A visitors building is also incorporated into the Las Perillas plant.

The reinforced-concrete substructures provide two floors: the motor floor at ground level and the pump floor 17 feet lower. The 38-cfs pumping units are located on the lower floor, while the motors for the 112-cfs units are on the upper floor directly above the pumps.

Suction tubes with 90-degree bends were formed in the concrete for the 112-cfs pumps, whereas steel intake bells were cast into the front wall for the 38-cfs units.

The substructures were constructed in three structurally independent monoliths with shear keys at abutting faces to prevent differential vertical movement. Vertical buttressed walls near the heel of the plant key the structure to the foundation and provide stability against sliding.

The superstructures are similar to those of other plants of the State Water Project: lightweight, metal, sandwich panels and welded steel T-decking mounted on rigid steel frames as discussed in Chapter I of this volume. An overhead bridge crane, supported by the superstructure columns, is provided at each plant: a 20-ton crane at Las Perillas and a 25-ton crane at Badger Hill.

At Las Perillas, the visitors building is constructed of cast-in-place reinforced concrete and is adjacent to the service bay end of the plant. It contains a stairway and a balcony that opens onto a mezzanine over the plant control room and office.

Design live loads used for some areas of the plant were:

Motor floor	500 psf or AASHO H-20
Pump floor	400 psf
Intake deck	300 psf or 4,000 lbs. concentrated
Mezzanine	125 psf
Stairways	100 psf
Roof	20 psf
Crane access platforms	250 psf
Wind	25 psf
Earthquake	0.5g

Both plants are founded on interbedded sand and clay-type soils. Under normal operating conditions, the maximum bearing pressures are approximately 2,600 pounds per square foot (psf), disregarding uplift. Under assumed earthquake loading, the pressure would increase to about 4,000 psf.

Waterways

Intake Facilities. Intake facilities at each of these plants include a channel transition, trashracks, stoplogs, bulkhead gates, formed concrete suction tubes for the 112-cfs pumps, and steel bell intakes for the 38-cfs units.

Channel transitions are fully concrete-lined, 76 feet - 3 inches long with the bottom width varying from 8 feet at the beginning of the transitions to 96 feet at the plants. An underdrain system was installed under each transition to provide a means of reducing uplift pressures on the lining. Drains are piped into a special drainage sump located in the plant structure. Sump pumps are operated, only as necessary, to maintain the ground water level below that of the forebay.

Trashracks were installed at the face of the plant structure. They are fabricated in panels of vertical steel bars, spaced to provide 3-inch clear openings. When in place, they are in a sloping position with one intermediate support. They are designed to withstand a differential head equal to two-thirds of the submerged depth of the rack when the canal water surface elevation is at a maximum. No mechanical raking equipment has been installed; however, a severe tumbleweed problem exists and raking equipment is being considered.

Stoplogs are provided to permit dewatering of one unit at a time at each plant. They were constructed in panels with a structural steel frame, steel skinplate, and rubber waterseals. The panels are interchangeable; three panels are required to dewater a 112-cfs pump and two for a 38-cfs pump. Stoplog slots were formed in the concrete piers just behind (downstream) the trashracks.

Steel slide gates were installed at the entrance of the suction tubes for the 112-cfs units. They can be operated manually or by a portable electric operator provided for each plant.

A butterfly valve was installed between the intake bell and pump at each 38-cfs unit to permit dewatering the pump without resorting to the use of stoplogs.

Pump Discharge Lines. Six pumps at each plant lift water through two parallel, buried, pump discharge lines into the next reach of the Coastal Branch of the California Aqueduct. At both plants, flows from Pumps Nos. 1, 2, 3, and 4 are combined by a manifold into the right discharge line, a 78-inch-diameter buried pipe. Similarly, a manifold at each plant combines flows from Pumps Nos. 5 and 6 into the 78-inch-diameter left discharge line. The length of the discharge system from pumping plant to the gated canal outlet is 258 feet at Las Perillas and 3,430 feet at Badger Hill.

Each pump discharge line is designed to deliver 225 cfs, with a maximum dynamic head of 61 feet at Las Perillas and 163 feet at Badger Hill. However, the maximum design head, including abnormal surge pressure due to power failure when the plant is operating at full capacity, is 73 feet at Las Perillas and 222 feet at Badger Hill.

Component features of these discharge lines were designed using criteria developed for pumping plants and discharge lines as described in Chapter I of this volume.

There are three distinct component features of the pump discharge lines at Badger Hill and Las Perillas Pumping Plants: (1) the articulation, (2) the manifold, and (3) the discharge lines.

Articulation. Each pump discharge line has two sleeve couplings placed adjacent to a length of casing

Figure 382. Articulations—Las Perillas

Figure 383. Manifolds—Las Perillas

pipe. This allows for settlement of the backfill around the discharge lines and for differential settlement between the manifold header and the pumping plant (Figure 382).

Manifold Sections. The Las Perillas manifold extends 115 feet from pumping plant to discharge line. The Badger Hill manifold extends 198 feet from pumping plant to Badger Hill Pipeline. Both manifolds are similar. The left manifold consists of two 48-inch-diameter steel pipes and an eccentric taper joining the 48-inch-diameter pipes to a 78-inch-diameter pipe. The right manifold consists of three 30-inch- and one 48-inch-diameter steel pipes connected by a header pipe and an eccentric taper to a 78-inch-diameter pipe (Figure 383). A 12½-foot horizontal spacing of the 78-inch-diameter Las Perillas discharge lines facilitated single-trench construction, whereas spacing of Badger Hill manifold outlet pipes was increased to 36 feet to facilitate two-stage construction of the connecting Badger Hill Pipeline. The change in diameter of the manifold header allows for a gradual change in velocity and minimizes head losses. The angle of intersecting pipes is 60 degrees.

Concrete anchors and thrust blocks were installed at bends and tapers.

Las Perillas Discharge Lines. Las Perillas discharge lines consist of two parallel, 78-inch-inside-diameter, buried, steel pipelines 143 feet long extending from the manifolds to the upper canal headworks. Stiffener rings were not required to withstand external pressures.

Flowmeters were installed in each discharge line for monitoring flows diverted to the Coastal Branch of the California Aqueduct. The following section on mechanical features contains the details of this installation.

Badger Hill Pipelines. Badger Hill pipelines extend 3,232 feet from the manifolds to the upper canal headworks. The right pipeline is a 78-inch-diameter, buried, steel pipe that was installed with the manifolds. The left pipeline is a 78-inch-diameter, reinforced-concrete, cylinder pipe (not prestressed) that was installed under a second contract.

Mechanical Features

General

Mechanical installation includes six pumps and discharge valves, one equipment-handling crane, and auxiliary equipment in each plant.

Chapter I of this volume contains information on the mechanical equipment in these plants which is common to other plants. Information and descriptions unique to these plants are included in the following sections.

Equipment Ratings

Pumps

Las Perillas Pumping Plant

Manufacturer:	Pumps Nos. 1, 2, and 3—Baldwin-Lima-Hamilton Corp.	
	Pump No. 4—Byron-Jackson	
	Pumps Nos. 5 and 6—Allis-Chalmers Mfg. Co.	
Type:	Pumps Nos. 1, 2, and 3—Horizontal-shaft, single-stage, split-case, centrifugal	
	Pump No. 4—Vertical, turbine	
	Pumps Nos. 5 and 6—Vertical, centrifugal	
	Pumps Nos. 1, 2, and 3	
	Discharge, each:	38 cfs
	Total Head:	61 feet
	Speed:	720 rpm
	Guaranteed Efficiency:	87.0%
	Pump No. 4	
	Discharge:	112 cfs
	Total Head:	59 feet
	Speed:	600 rpm
	Pumps Nos. 5 and 6	
	Discharge, each:	112 cfs
	Total Head:	60 feet
	Speed:	450 rpm
	Guaranteed Efficiency:	86.0%

Badger Hill Pumping Plant

Manufacturer:	Pumps Nos. 1, 2, and 3— Baldwin-Lima-Hamilton Corp.	
	Pumps Nos. 4, 5, and 6— Byron-Jackson	
Type:	Pumps Nos. 1, 2, and 3— Horizontal-shaft, single-stage, split-case, centrifugal	
	Pumps Nos. 4, 5, and 6— Vertical, turbine	
	Pumps Nos. 1, 2, and 3	
	Discharge, each:	38 cfs
	Total Head:	163 feet
	Speed:	900 rpm
	Guaranteed Efficiency:	87.0%
	Pump No. 4	
	Discharge:	112 cfs
	Total Head:	162 feet
	Speed:	600 rpm
	Guaranteed Efficiency:	88.5%
	Pumps Nos. 5 and 6	
	Discharge, each:	112 cfs
	Total Head:	162 feet
	Speed:	514 rpm
	Guaranteed Efficiency:	88.5%

Note: Pumping Units Nos. 4, 5, and 6, presently installed at both Las Perillas and Badger Hill Pumping Plants, were funded separately and installed by a local water district to utilize excess water that is available during the water demand buildup.

Pump Discharge Valves

Manufacturer:	Units Nos. 1, 2, 3, and 4— Darling Valve and Manufacturing Co.
	Units Nos. 5 and 6— Willamette Iron and Steel Co.
Type and Size:	Units Nos. 1, 2, and 3— 20-inch, rubber-seated, spherical
	Unit No. 4— 36-inch, rubber-seated, spherical
	Units Nos. 5 and 6— 36-inch, fixed-metal seat, spherical

Intake Gates and Valves

Manufacturer:	Units Nos. 1, 2, and 3— BIF Division of New York Air Brake Co.
	Units Nos. 4, 5, and 6— Jeffrey Manufacturing Co.
Type and Size:	Units Nos. 1, 2, and 3— 30-inch, rubber-seated, butterfly
	Units Nos. 4, 5, and 6— 78-inch by 78-inch, slide gate

Equipment Handling—Cranes

Manufacturer:	Crane Veyor Corp.
Type:	Double-girder, top-riding, three motor electric for Class A service

Pumps

The three 38-cfs pumps in each plant are horizontal-shaft, single-stage, centrifugal, double-suction volute with horizontal intake and discharge, and split-case with the case separation in the horizontal plane of the shaft centerline. Intake and discharge diameters are 24 inches and 20 inches, respectively (Figure 384).

These pumps are driven through Falk, gear-type, flexible couplings by synchronous motors rotating in a counterclockwise direction as viewed from the motor end. Pumps and motors are mounted on an integral, fabricated, steel base. The base is anchored by foundation bolts embedded in a reinforced-concrete pedestal on the pump floor. Impeller, shaft, bearings, and both casing and impeller wear rings are accessible when the top portion of the casing is removed. Casing, of gray iron, is bolted together in the horizontal centerline and doweled to ensure alignment.

The impellers are a cast bronze-enclosed type. They are dynamically balanced, keyed to the shafts, and locked into position between the shaft sleeves.

Shafts are alloy steel, machine-ground, and polished. Bronze cast sleeves protect the shafts where exposed to water. They are mounted in ball bearings, with thrust taken in the outboard bearings and end float permitted in the bearings at the coupling end of the shafts.

Seal rings are of cast bronze. The outer rings of bronze are in two halves with shoulders on the lower halves which bear against the casing covers to prevent rotation. The impeller rings, also of bronze, are one-piece and bear on shoulders turned on the ring land of the impellers.

Unit No. 4 at Las Perillas Pumping Plant and Units Nos. 4, 5, and 6 at Badger Hill Pumping Plant are one-stage, vertical, circulator pumps. (Plants were initially designed for installation of vertical centrifugal pumps as Units Nos. 4, 5, and 6.) Each pump consists of the bowl assembly, driver-to-pump coupling assembly, suction plate, discharge elbow, motor barrel, Dresser coupling, and shaft seal assembly.

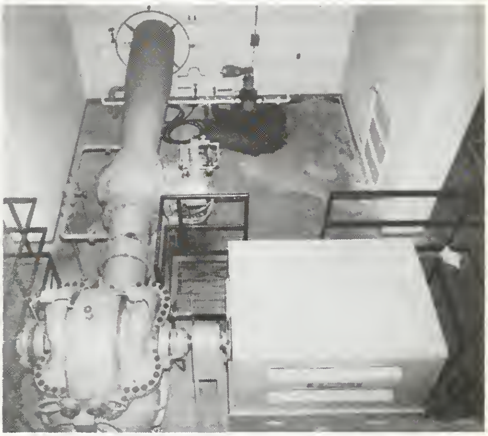

Figure 384. Horizontal Pump Installation—Las Perillas

Units Nos. 5 and 6 at Las Perillas Pumping Plant are vertical centrifugal pumps that have a fabricated plate steel bearing bracket, suction nozzle and suction spool, cast-iron back cover, nodular-iron pump casing, 11½ to 13% chrome steel hardened impeller and casing rings, babbitt-lined sleeve-type bearing, and miscellaneous piping and instrumentation (Figure 385).

Pump Discharge Valves

Spherical valves were installed on the discharge side of all units at both plants to prevent backflow through the pumps. They also serve as shutoffs to isolate the pumps from the discharge line for servicing and maintenance.

Double, rubber-seated, 20-inch-diameter, spherical valves were installed on all 38-cfs units. A single, fixed-metal seat, 36-inch-diameter, spherical valve was installed on Units Nos. 5 and 6 while Unit No. 4 has a double, rubber-seated, 36-inch-diameter, spherical valve.

Each valve is actuated by an operator composed of a double-acting hydraulic cylinder linked through a crosshead and connecting links to a lever mounted on the valve shaft. The operator is powered by a 1,000-pound-per-square-inch hydraulic power unit and will operate on a minimum pressure of 750 pounds per square inch. Units Nos. 1, 2, 3, and 4 are connected to one hydraulic system, and Units Nos. 5 and 6 are connected to another.

Each hydraulic system consists of a hydraulic power unit, an accumulator bottle rack, pressure switches, and gauges mounted on a panel attached to the accumulator rack.

The hydraulic power unit (Figure 386) consists of a 100-gallon oil reservoir, two electrically driven hydraulic pumps with associated relief valves and filters, and a hand pump, all mounted on the reservoir. Also installed in the power unit reservoir is a visual liquid level gauge, a thermostatically controlled oil heater, a temperature gauge, two float switches for remote indication of low oil level and for stopping the electric motor in case of low oil level, and a filler-breather unit.

The bottle rack contains bladder accumulators with two nitrogen bottles connected to the gas end of the accumulators for additional precharge volume. A third nitrogen bottle on the rack stores pressurized nitrogen for makeup of accumulator precharge as required.

Equipment Handling—Cranes

Each plant has an electric, overhead, traveling, bridge crane powered by a 208-volt, 3-phase, 60-hertz motor with floor-operated pendant controls. The crane is used for assembly and maintenance of plant equipment, including main pumps, pump drive motors, and discharge valves.

Characteristics of the cranes are:

Las Perillas Pumping Plant

Capacity	20 tons
Span	30 feet—2¾ inches
Hoist hook lift	37 feet—6 inches

Badger Hill Pumping Plant

Capacity	25 tons
Span	30 feet—2¾ inches
Hoist hook lift	37 feet—6 inches

The hoists are package units, each powered by a 15/5-horsepower 1,800/600-rpm motor, with electric brake and operate at speeds of 11 feet per minute (fpm) or 3.6 fpm. Trolley speed is 5-step variable up to 50 fpm, and bridge speed is 5-step variable up to 75 fpm. Limit switches are provided for all crane motions.

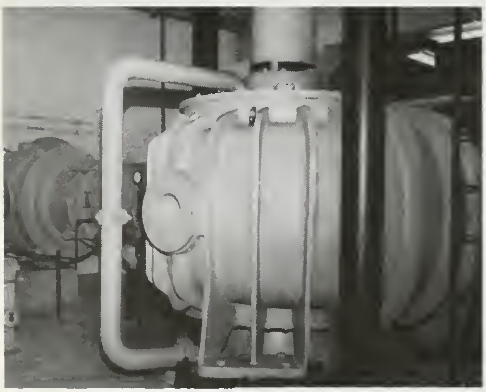

Figure 385. Vertical Centrifugal Pump Installation—Las Perillas

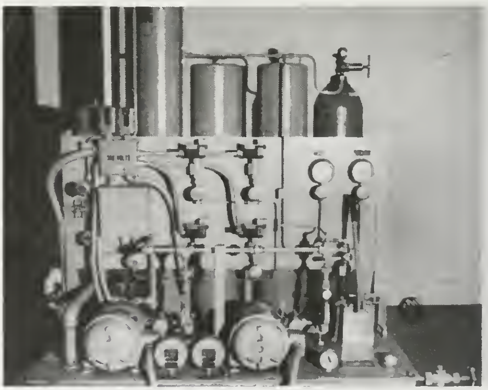

Figure 386. Hydraulic Power Unit—Las Perillas

Hydraulic Transients

Surge and reverse speed controls on each pump and motor are provided by single-speed pump discharge valve closure.

The pumps on Units Nos. 5 and 6 at Las Perillas Pumping Plant have reverse runaway speeds in excess of the allowable reverse speeds of the motors. Hydraulic transient studies on these units indicated that the reverse speed upon power failure could be reduced to approximately 100 rpm if the 36-inch spherical valve was closed in 10 seconds. Upsurge and downsurge conditions experienced during the 10-second closure were within safe operating limits. Field tests on these units have verified the analysis.

The pump discharge valves all open and close at an approximately uniform rate, and the closing times are the same for normal or emergency conditions.

Auxiliary Service Systems

Auxiliary service systems at the plant are described in Chapter I of this volume.

Intake Gates and Valves

(Units Nos. 1, 2, and 3)

Each 38-cfs pump has a butterfly valve in the suction line. They are 30-inch-diameter, manually operated, cast steel, flanged-end, rubber-seated, tight-closure, butterfly type conforming to AWWA Standard C504, Class 50-16.

The manual operator has a 4:1 gear ratio and a limit switch to prevent starting the pump with the butterfly valve not fully open.

(Units Nos. 4, 5, and 6)

Slide gates were installed at the intake face of Units Nos. 4, 5, and 6. Each gate consists of a gate body, wall thimble, flush bottom seating surface, guide channels, stem, floorstand, and manual operator. Each gate is 78 inches wide by 78 inches high and operates at seating heads from 0 to 20 feet. A resilient seal is molded of neoprene in a triangular cross section and is retained on the disc face by stainless-steel keepers. A bronze thrust nut is mounted on the thrust nut retainer and transmits the opening and closing forces.

A portable 120-volt operator is provided for the three gates at each plant. It consists of a portable, reversible, electric drill with an adaptor to fit operator input shafts (Figure 387).

Flow Tubes (Las Perillas Pumping Plant)

Flow tubes of the modified Venturi type were installed in two 78-inch discharge pipes. They are Dall Model DFTW-6, manufactured by BIF Division of the New York Air Brake Co.

Instrumentation consists of a transmitter located at the flow tube and a flow indicator and totalizers located in the plant control room.

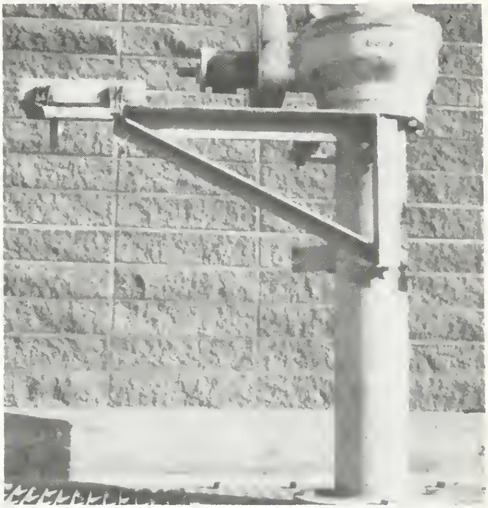

Figure 387. Gate Operator Stand

Electrical Features

General

Electrical installations at the plants are sufficiently similar for common discussion. The difference in ratings of the motors and transformers were not great enough to affect the system design. Electrical drawings included in this chapter are for the Las Perillas Pumping Plant and are typical of both plants.

Description of Equipment and Systems

A transformer bank reduces 69 kV to motor voltage. Four single-phase transformers were selected, one being a spare. The low-voltage winding neutrals are grounded through a resistor to limit the ground fault current. Lightning arresters and fuses in the switchyard protect the transformers (Figure 388).

Figure 388. Switchyard—Las Perillas

The motors are connected to the low-voltage side of the power transformers by magnetic starters and current-limiting fuses. Motors are started at full-voltage with the pump case full of water.

The switchgear includes the motor controllers, excitation equipment, and field application equipment. Protective relaying, instruments, meters, and control devices are also included. An adjacent cabinet lineup includes incoming bus, revenue metering equipment, and station service breakers (Figure 389). The station service transformer is located on the floor below the switchgear.

Plant pumping and auxiliary equipment is controlled manually from local controls rather than from a control room in the building. Remote controls are normally used for operation and monitoring functions and are described in Volume V of this bulletin.

Figure 389. 5-kV Switchgear Assembly and 600-Volt Motor Control Center—Las Perillas

Equipment Ratings

Motors

3-phase, 60 Hz, 100% power factor

Motors Nos. 1, 2, and 3—Las Perillas Pumping Plant

Manufacturer: Westinghouse Electric Corporation
Type: Horizontal, synchronous
Horsepower: 350
Volts: 2,300
Speed: 720 rpm

Motor No. 4—Las Perillas Pumping Plant

Manufacturer: Westinghouse Electric Corporation
Type: Vertical, synchronous
Horsepower: 1,000
Volts: 2,300
Speed: 600 rpm

Motors Nos. 5 and 6—Las Perillas Pumping Plant

Manufacturer: General Electric Company
Type: Vertical, synchronous
Horsepower: 1,000
Volts: 2,300
Speed: 450

Motors Nos. 1, 2, and 3—Badger Hill Pumping Plant

Manufacturer: Westinghouse Electric Corporation
Type: Horizontal, synchronous
Horsepower: 1,000
Volts: 4,000
Speed: 900 rpm

Motor No. 4—Badger Hill Pumping Plant

Manufacturer: Westinghouse Electric Corporation
Type: Vertical, synchronous
Horsepower: 2,750
Volts: 4,000
Speed: 600 rpm

Motors Nos. 5 and 6—Badger Hill Pumping Plant

Manufacturer: General Electric Company
Type: Vertical, synchronous
Horsepower: 3,000
Volts: 4,000
Speed: 514 rpm

Power Transformers—Las Perillas Pumping Plant

Manufacturer: Westinghouse Electric Corporation
Volts: 115/69-1.386 kV
kVA: 1,250
Connections: Delta-Wye
Type: OA

Power Transformers—Badger Hill Pumping Plant

Manufacturer: Westinghouse Electric Corporation
Volts: 115/69 2.4 kV
kVA: 3,333
Connections: Delta-Wye
Type: OA

Station Service—Las Perillas Pumping Plant

Transformer manufacturer: General Electric Company
Volts: 2,400—208Y/120
kVA: 225

Station Service—Badger Hill Pumping Plant

Transformer manufacturer: General Electric Company
Volts: 4,160—208Y/120
kVA: 150

Plant Reliability

No reservoir storage is available in the distribution systems of the service areas at the present time; consequently, the plants must provide maximum dependability and yet allow ease of maintenance.

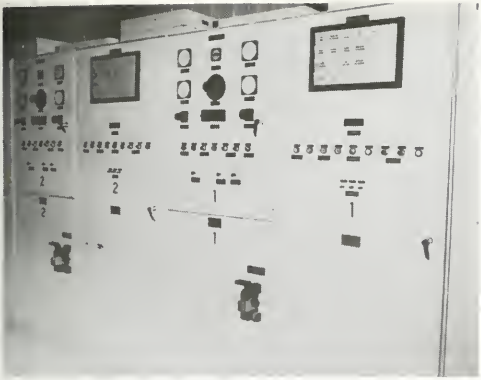

Figure 390. Synchronous Motor Controllers—Los Perillos

Motor controllers with current-limiting fuses were selected rather than circuit breakers primarily because they were considered to be more reliable and more economical (Figure 390). Motor size was within suitable limits for either choice. The shorter depth of the controller cabinet suited plant dimensions to better advantage.

Although the station service system was not designed with alternate equipment or circuits, all parts are standard and readily replaceable. Spare parts not in stock may be acquired within a few hours.

Four single-phase transformers were installed with cable drops from bus bars to their bushings. A transformer can be replaced by the spare without moving the spare. Power transformers are operated on 69 kV; however, the high-voltage side also has windings and bushings for 115-kV service. Voltage available was 69 kV when the plant was constructed, but the utility company intends to change voltage to 115 kV when warranted by developments in its service area. To benefit from lower rates, transformers were selected with dual voltages on the high-voltage side.

Selection of Motors

Cost difference between synchronous motors and induction motors with capacitors for power factor correction was not significant. The primary advantage of the synchronous motors for these plants was their constant speed for matching output of the two plants. Since there is essentially no freeboard for storage between the plants, this requirement became critical.

Motors of the sizes (Figure 391) required normally do not have air housings. Fire danger was considered too remote to justify the cost of enclosures and CO_2 protection. Motors are cooled by the building air-conditioning system rather than by individual air-to-water heat exchangers.

A static excitation system was selected for each motor. A separate excitation system was selected rather than a direct-connected system primarily because it was considered more reliable for ratings required. Rather than using one exciter for each motor, a common excitation system was considered. This choice would have lowered the overall plant reliability and was rejected. Rotating static exciters were also considered; however, there was not enough experience available to justify their use.

The motor voltage selected was 2,300 for Las Perillas and 4,000 for Badger Hill since this choice reduced costs. At Las Perillas, there was some cost advantage in using 2,300 volts; however, total installed horsepower at Badger Hill was considered sufficiently high to warrant 4,000 volts, thereby reducing the size of the low-voltage leads.

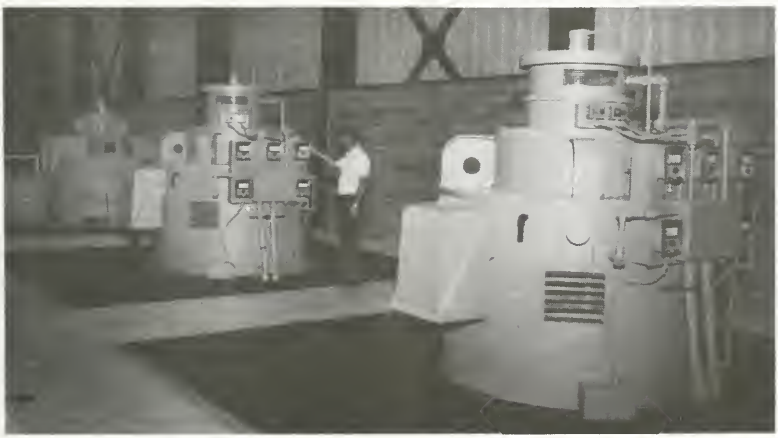

Figure 391. 1,000-Horsepower Synchronous Motors—Los Perillos

TABLE 8. **Major Contracts—Las Perillas and Badger Hill Pumping Plants**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Pumps	65-53	$94,166	$97,989	$3,856	5/23/66	4/27/68	Baldwin-Lima-Hamilton
Las Perillas and Badger Hill Pumping Plants	66-33	3,466,213	3,700,382	116,750	9/30/66	6/28/68	Fred J. Early, Jr., Co., Inc.
Motors	66-39	117,582	122,874	--	11/28/66	4/27/68	Westinghouse Electric Corp.

Construction

Contract Administration

The major construction and supply contracts for Las Perillas and Badger Hill Pumping Plants are shown in Table 8. The major construction contract was designated Specification No. 66-33 and included the following principal features: Las Perillas Pumping Plant, Badger Hill Pumping Plant, discharge lines, switchyards, electrical and mechanical work, and installation of materials and equipment furnished by the Department of Water Resources.

Excavation

Las Perillas. First-stage excavation of the Las Perillas Pumping Plant began in April 1966 and was completed four months later. The material excavated from the pumping plant site was used to construct a protective levee and the Las Perillas access road. The excess material was placed in a designated waste area. As excavation of the first stage continued, the dewatering system was modified several times, and a storage reservoir was constructed between the Pumping Plant and the protective levee.

The excavation was performed with scrapers and large dozers. When the first-stage excavation was completed to elevation 317 feet, five drainage wells were drilled from the first-stage bench to depths of 40 to 50 feet.

Badger Hill. The first-stage excavation of the Badger Hill Pumping Plant began in May 1966 and was completed five months later. Excavation of the site was performed with scrapers, large dozers, and a backhoe.

After the first few feet of progress, excessive moisture was encountered making excavation with rubber-tired equipment difficult. The access road and the Pumping Plant were excavated simultaneously. The material was placed in the access road embankment, the protective levee, and the designated waste area.

When ground water increased, the scrapers were replaced with a dragline. In July 1966, 11 wells were drilled to a depth of 50 feet; however, the flow of water into the excavation site continued to increase. The contractor then injected chemical grouting around the outer limits of the excavation in an attempt to seal off the infiltrating ground water. Forty-six well points then were installed around the perimeter on 4-foot centers and connected to a vacuum pump. Excavation proceeded by dragline using a barrel-type bucket. By September 1966, the number of well points had been increased to 86, and the substitution of a larger capacity pump adequately dewatered the excavation site (Figures 392, 393 and 394).

Figure 392. Plant Excavation—Badger Hill

Figure 393. Plant Excavation—Las Perillas

Figure 394. Start of Foundation for Badger Hill

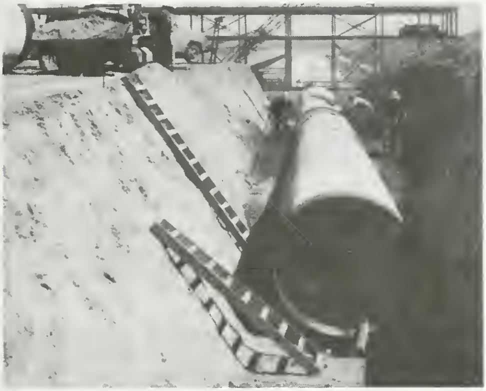

Figure 395. Installing 78-Inch-Diameter Discharge Line—Badger Hill

Figure 396. Discharge Lines—Las Perillas

Discharge Lines. Excavation for the Badger Hill discharge lines was performed with a backhoe using a 1½-cubic-yard bucket. The trench was overexcavated a minimum of 3 inches, and the bottom was bedded with pervious backfill. After the pipes were installed, the trench was backfilled with pervious material which was then consolidated by flooding and vibrating with concrete vibrators. Native material was dozed over the top of the pipe up to the level of the surrounding terrain.

Excavation for the Badger Hill manifolds and Las Perillas discharge lines and manifolds was performed with a ⅜-cubic-yard Gradall on the level areas and with a dozer and clamshell on the slopes. Manifold excavations were backfilled with sand and compacted by whacker machine compactors (Figures 395 and 396).

Concrete Placement

The first concrete was placed at Las Perillas and Badger Hill Pumping Plants in November 1966. The batch plant was a 2-cubic-yard tilt mixer (Figure 397). Water was obtained from nearby wells. The pH of the water used was at the upper limit of acceptability for concrete. Concrete was hauled from the batch plant to the vicinity of placement in 8-cubic-yard trucks, where a crane with a 1-cubic-yard bucket delivered the concrete to point of placement.

The Department determined concrete mix proportions, took slump tests, and made test cylinders. Cement from some shipments had a false set; therefore, the amount used was increased 10% when this cement was proportioned in the mix. Crushed ice was used for a portion of the mixing water when necessary to maintain the temperature of the concrete below 75 degrees Fahrenheit.

Electrical-Mechanical Installations

Electrical Cable. In November 1966, the first electrical cable and a small tractor-mounted trencher were delivered, and trenching for the main grounding

Figure 397. Contractor's Batch Plant

grid under the Badger Hill Pumping Plant site commenced. The rough excavation for the plant base had penetrated approximately 7 feet below the water table. Subsequent heavy rainfall hindered the excavation and backfilling of the cable trenches.

Valves. Pump discharge valves were manufactured and installed in accordance with approved submittals. There was an unusual amount of difficulty in installing and obtaining required seating and operating characteristics. The valves had to be removed and seat rings replaced at Badger Hill Pumping Plant. The coating on the inside of the valves revealed a blister effect which could reduce longevity. Tests were performed in accordance with specifications.

Gates. Suction intake gates were shop-inspected, and a coating was applied at the job site in accordance with specifications.

Overhead Cranes. The overhead cranes arrived at Las Perillas and Badger Hill Pumping Plants in September 1967. Considerable adjustment in the controls and crane rails was necessary after setting the cranes on the rails. The cranes were approved in accordance with submittals and tested with the weight requirements of the specifications.

Power Transformers. Since the power transformers were not scheduled for delivery until several months after Badger Hill Pumping Plant was to be operational, special provisions were made for temporary transformers. Three used, single-phase, 1,000-kVA transformers were rented from the Southern California Edison Company and four used, single-phase, 500-kVA transformers were purchased from an Oregon utility company which had planned to scrap them. All of these were delivered to the plant on November 1, 1967 with installation being completed by January 22, 1968. They performed satisfactorily during start-up tests and were used through the first three months of operation.

Permanent transformers replaced the temporary units on April 15, 1968 and, after successfully passing the required electrical tests, were placed in service (Figure 398).

Motors. Installation of motors began in October 1967. The last motor was installed in January 1968. The work consisted of designing, manufacturing, installing, and testing the three 1,000-horsepower motors for the horizontal pumps at Badger Hill Pumping Plant and three 350-horsepower motors for the Las Perillas Pumping Plant.

No changes were made in design or during manufacture of units, and no special problems occurred during installation. The equipment and procedure used for this installation and testing were routine. All motors passed the high-voltage insulation and other tests performed in accordance with specifications.

Pumps. Installation of pump bases on pedestals commenced in October 1967. Unit No. 2 was the last pump installed at Badger Hill Pumping Plant and the installation was completed in January 1968, after a delay for repairs. Earlier, two pumps had to be disassembled, sandblasted, and recoated because the initial coating did not bond properly. A problem of noise and vibration, which was attributed to improper setting of the ball valves in some of the units, required correction.

Figure 398. Installing Bushings on Transformers at Badger Hill

Figure 399. Installing Pumps at Las Perillas

By agreement dated May 15, 1968, between the Berrenda Mesa Water District (a member unit of the Kern County Water Agency) and the Department, the District furnished and installed Pumping Unit No. 4 in each pumping plant and administered the work. An agreement dated May 8, 1969, between the District and the Department, provided for the District to award contracts for furnishing and installing Pumping Units Nos. 5 and 6 in each pumping plant and the second discharge line at the Badger Hill Pumping Plant (Figures 399 and 400). This latter contract was administered by the Department.

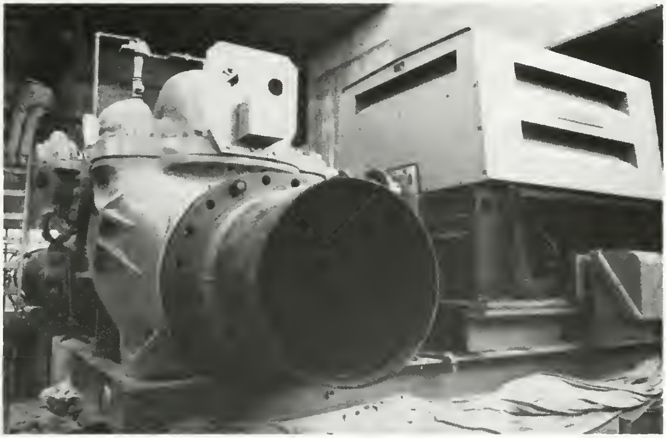

Figure 400. Pump and Motor Installation at Badger Hill

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 401 through 421).

Figure Number	
401	General Site Plan—Las Perillas
402	General Site Plan—Badger Hill
403	Motor Floor Plan—Las Perillas
404	Pump Floor Plan—Las Perillas
405	Longitudinal Section—Las Perillas
406	Transverse Section—Las Perillas
407	Manifold Details—Badger Hill
408	Pipeline—Badger Hill
409	Pipeline (Continued)—Badger Hill
410	Pump Discharge Valve—Hydraulic System
411	Overhead Traveling Crane
412	Suction Intake Gates—112-cfs Units
413	Flow Tubes—Las Perillas
414	Suction Intake Dewatering Valve
415	Piezometer Piping—Las Perillas
416	Pump Discharge Valve—Bypass System
417	Domestic Plumbing Systems—Las Perillas
418	Plant Single-Line Diagram—Las Perillas
419	Station Service Schematic—Las Perillas
420	Control Equipment—Lineup
421	Control Equipment—Elevation—Las Perillas

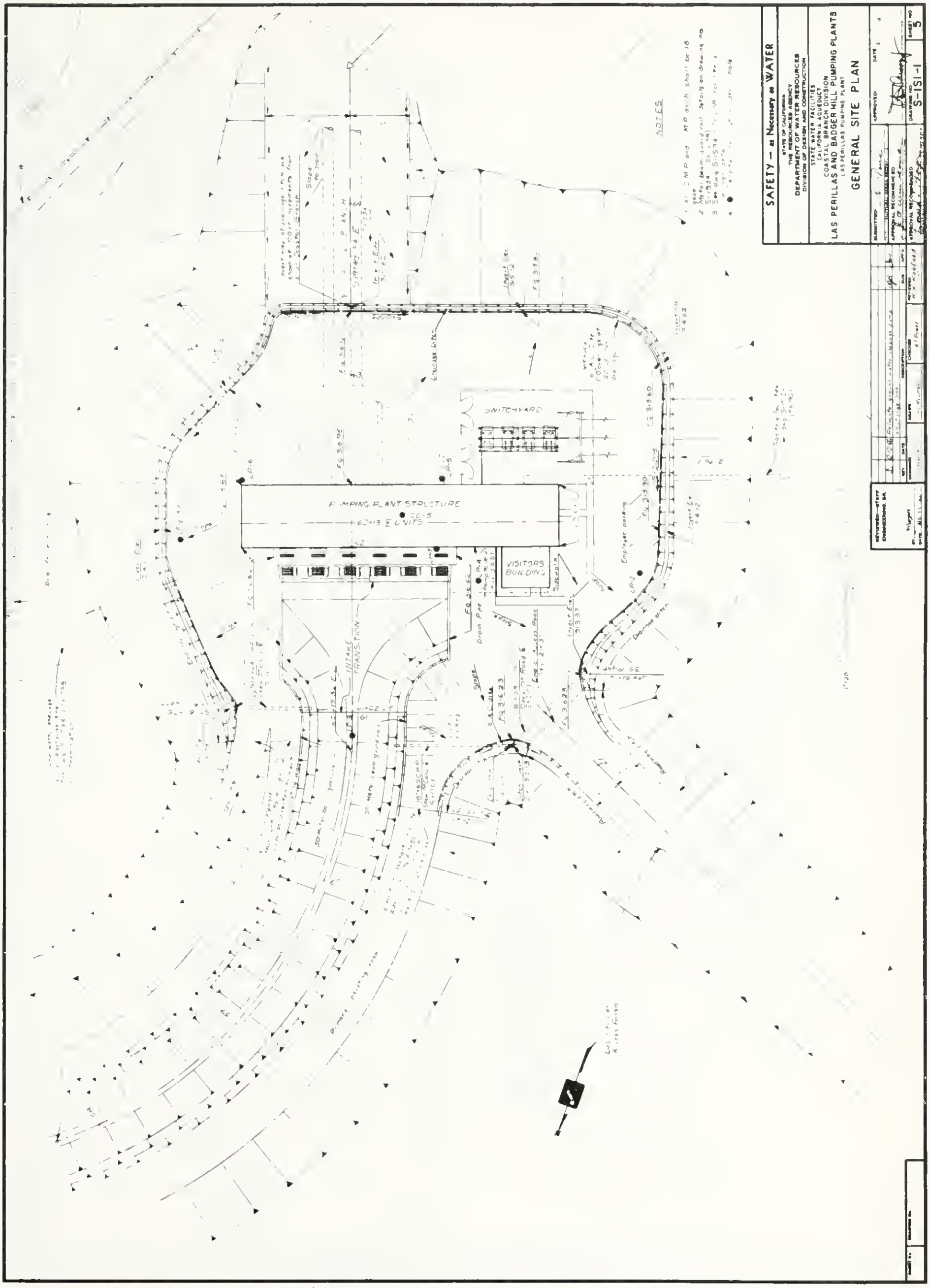

Figure 401. General Site Plan—Las Perillas

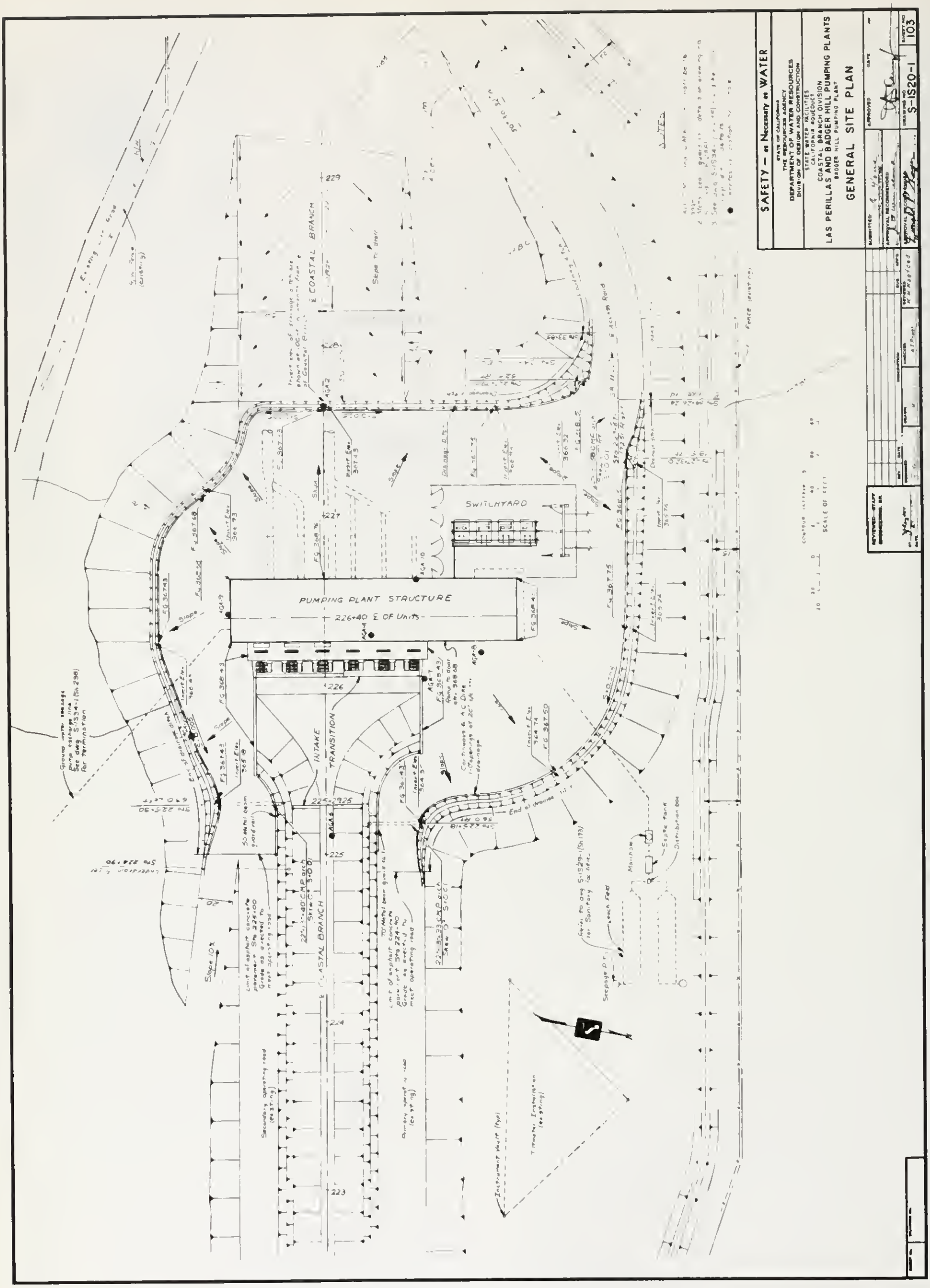

Figure 402. General Site Plan—Badger Hill

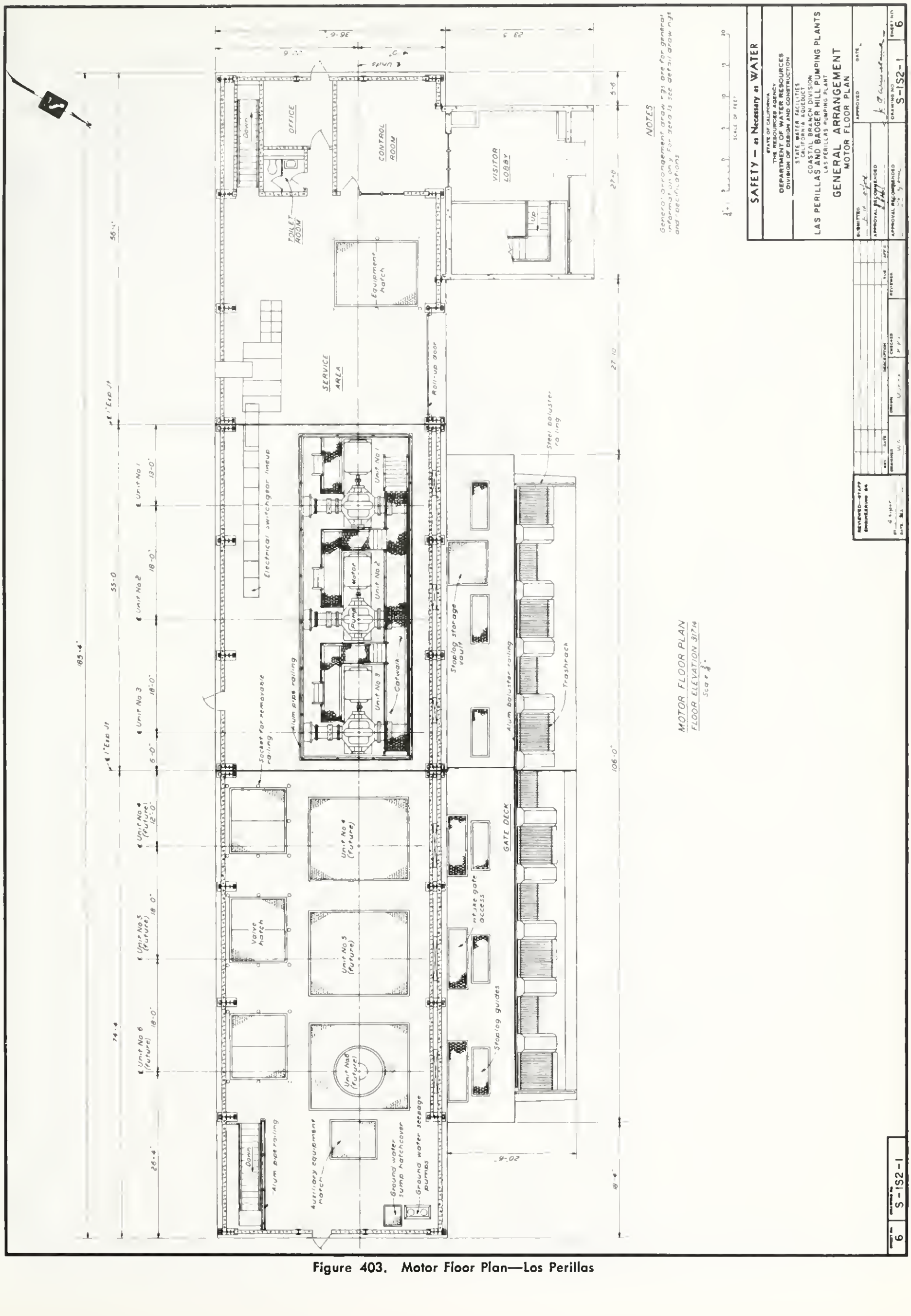

Figure 403. Motor Floor Plan—Los Perillas

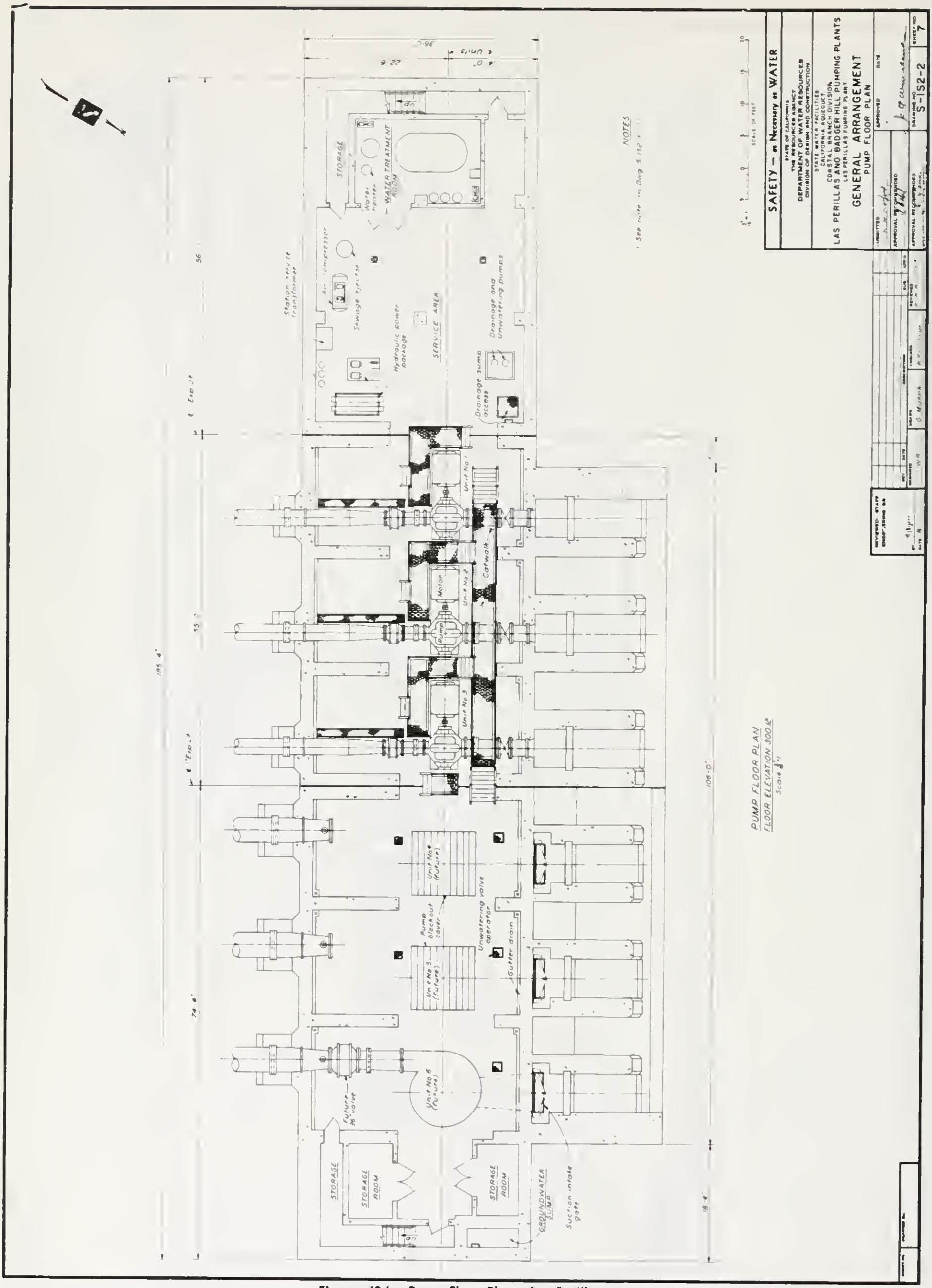

Figure 404. Pump Floor Plan—Las Perillas

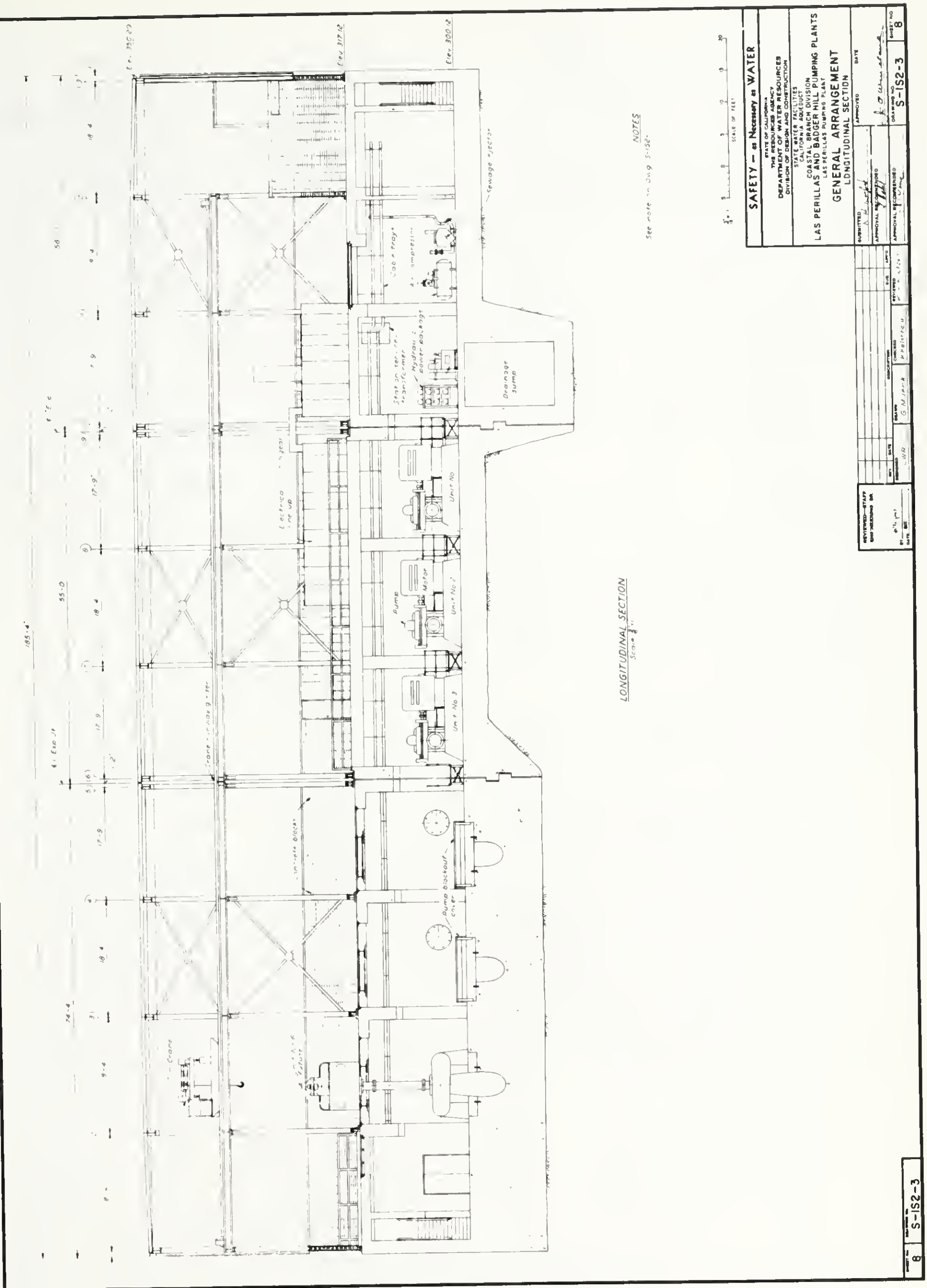

Figure 405. Longitudinal Section—Las Perillas

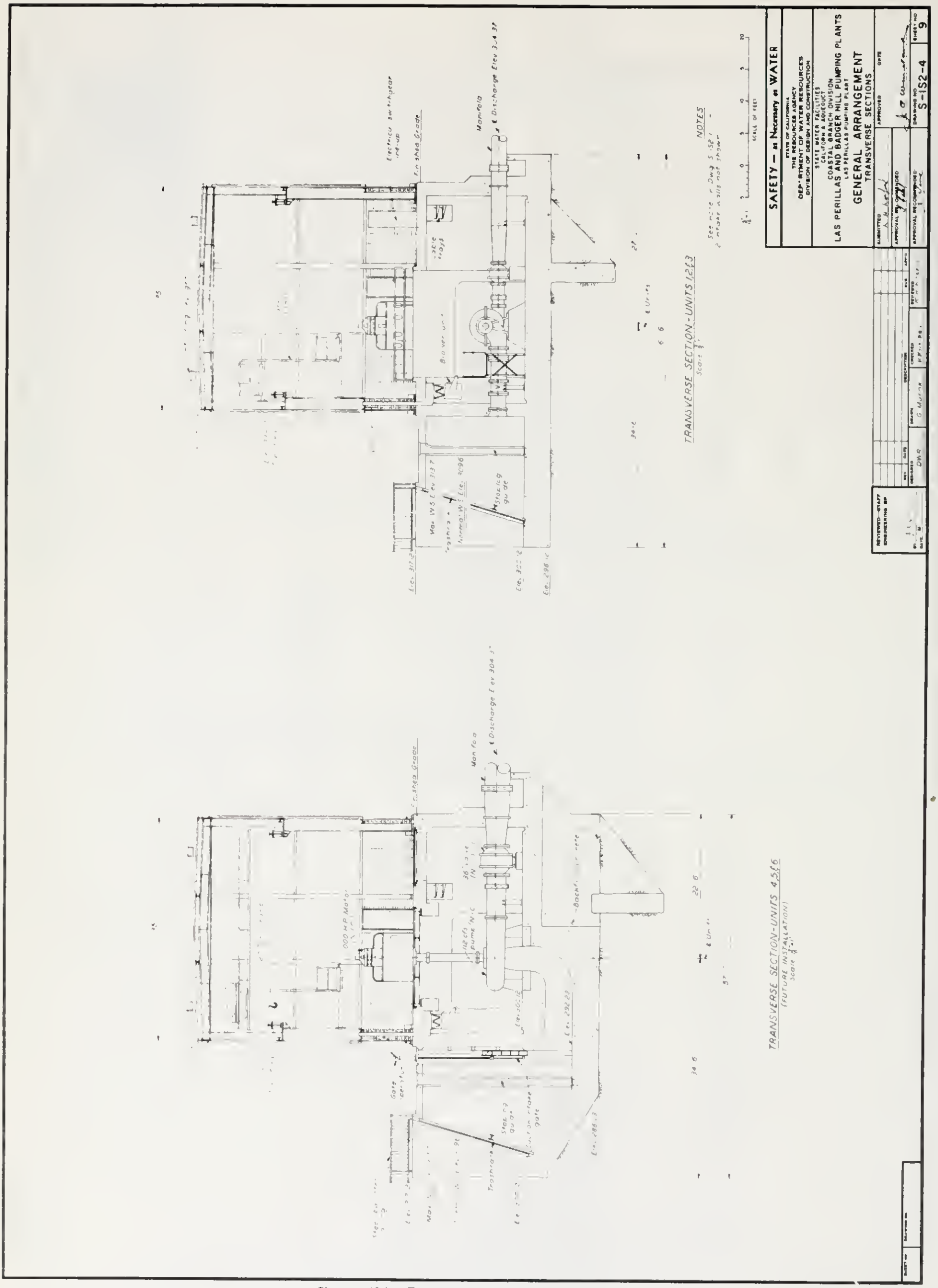

Figure 406. Transverse Section—Las Perillas

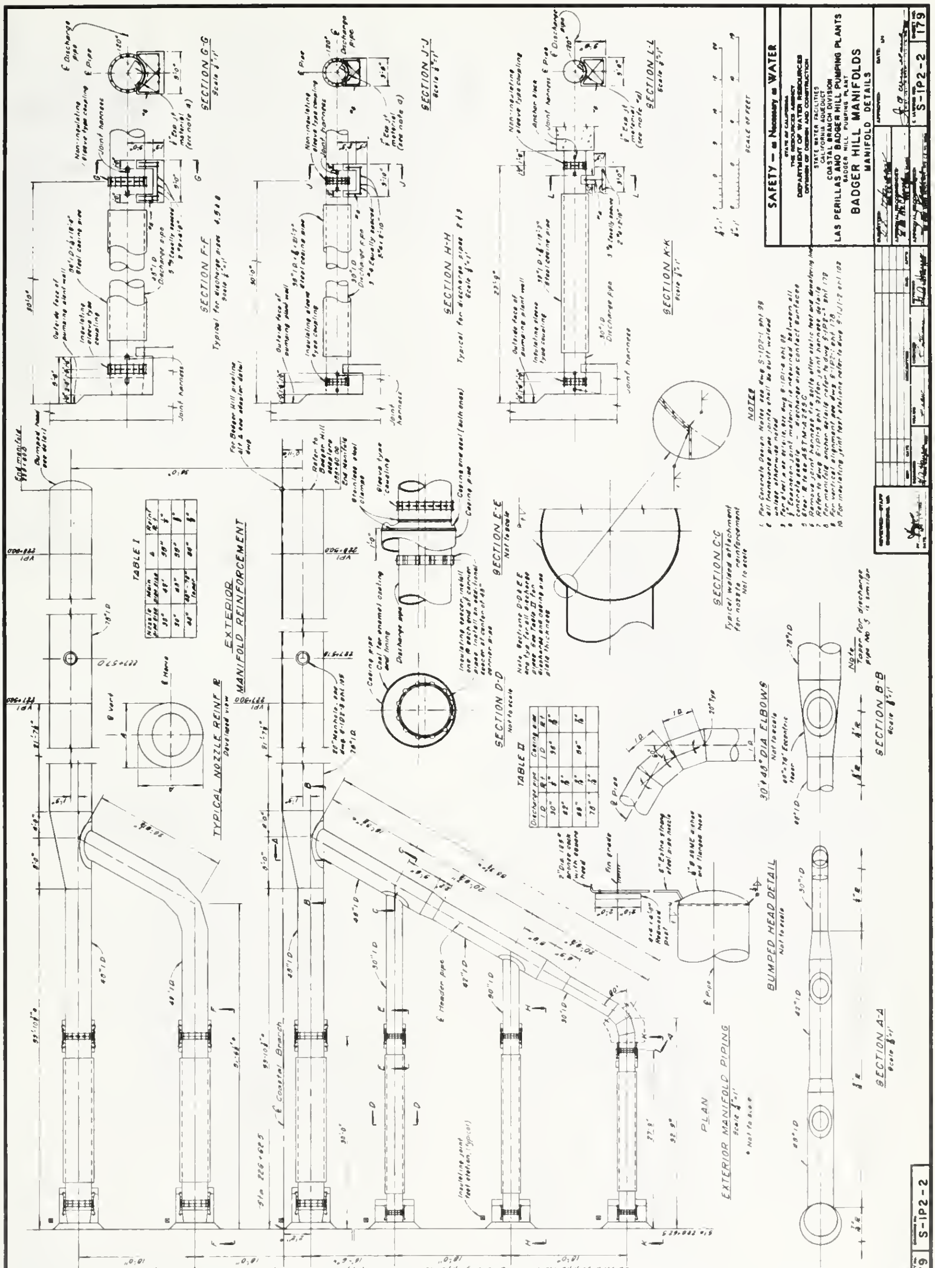

Figure 407. Manifold Details—Badger Hill

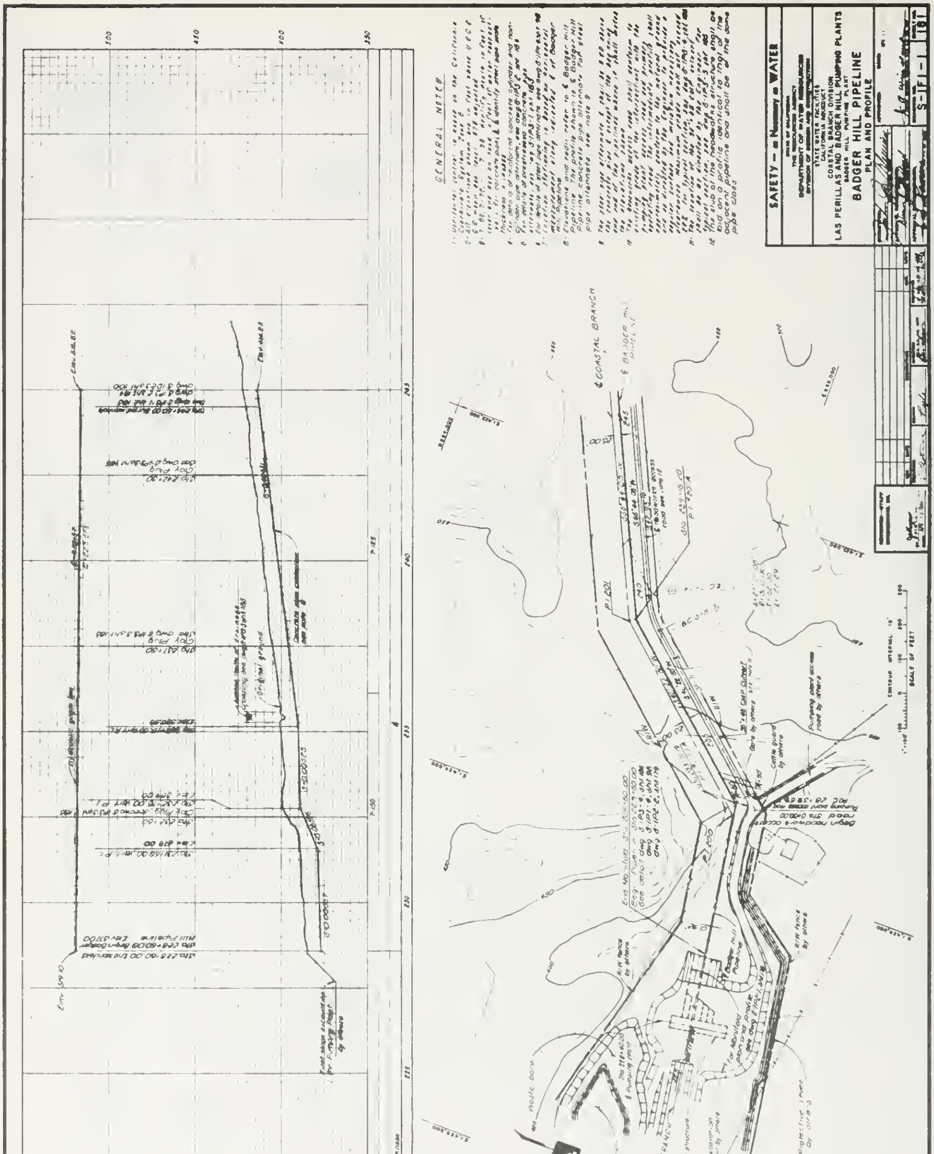

Figure 408. Pipeline—Badger Hill

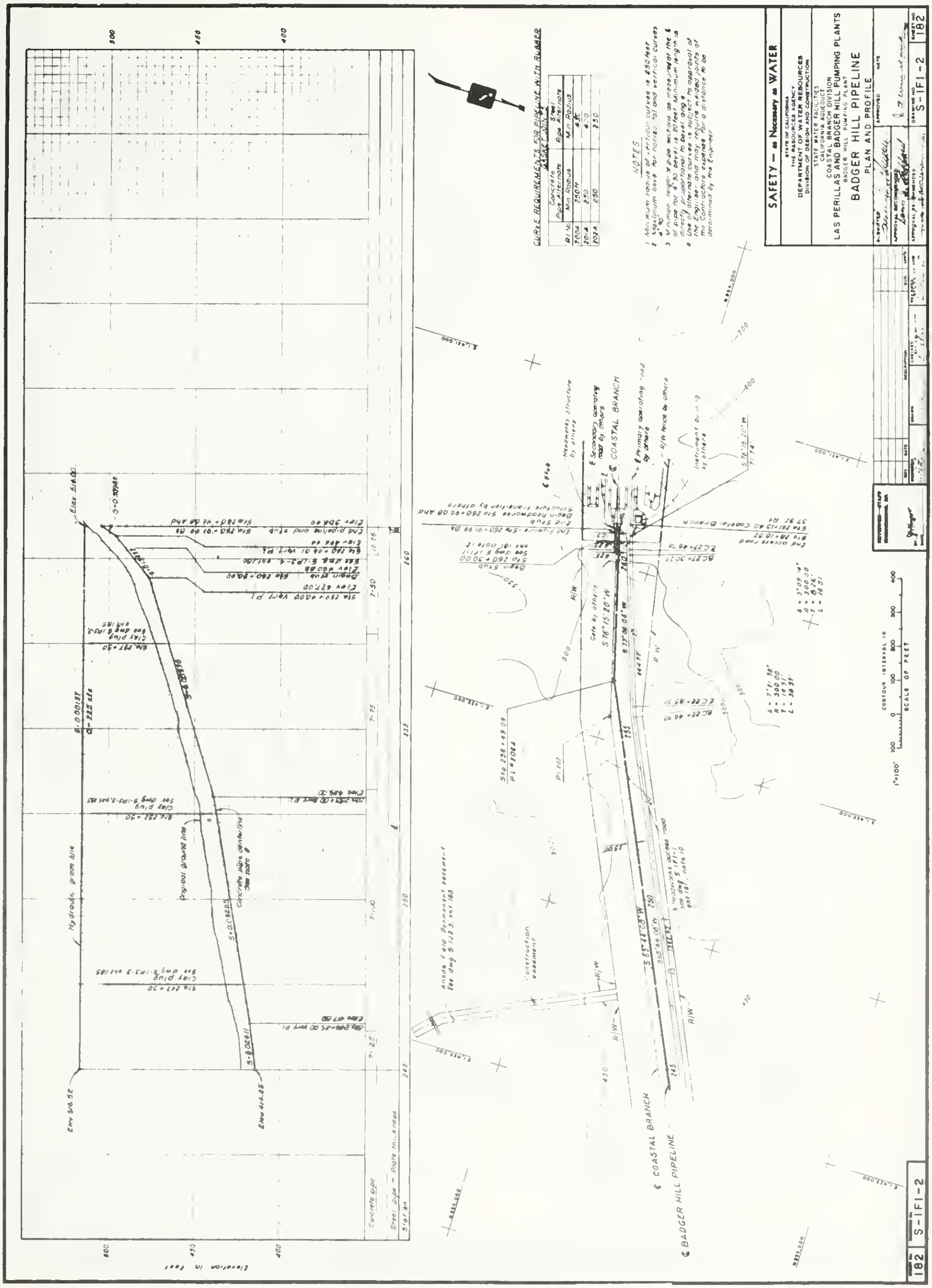

Figure 409. Pipeline (Continued)—Badger Hill

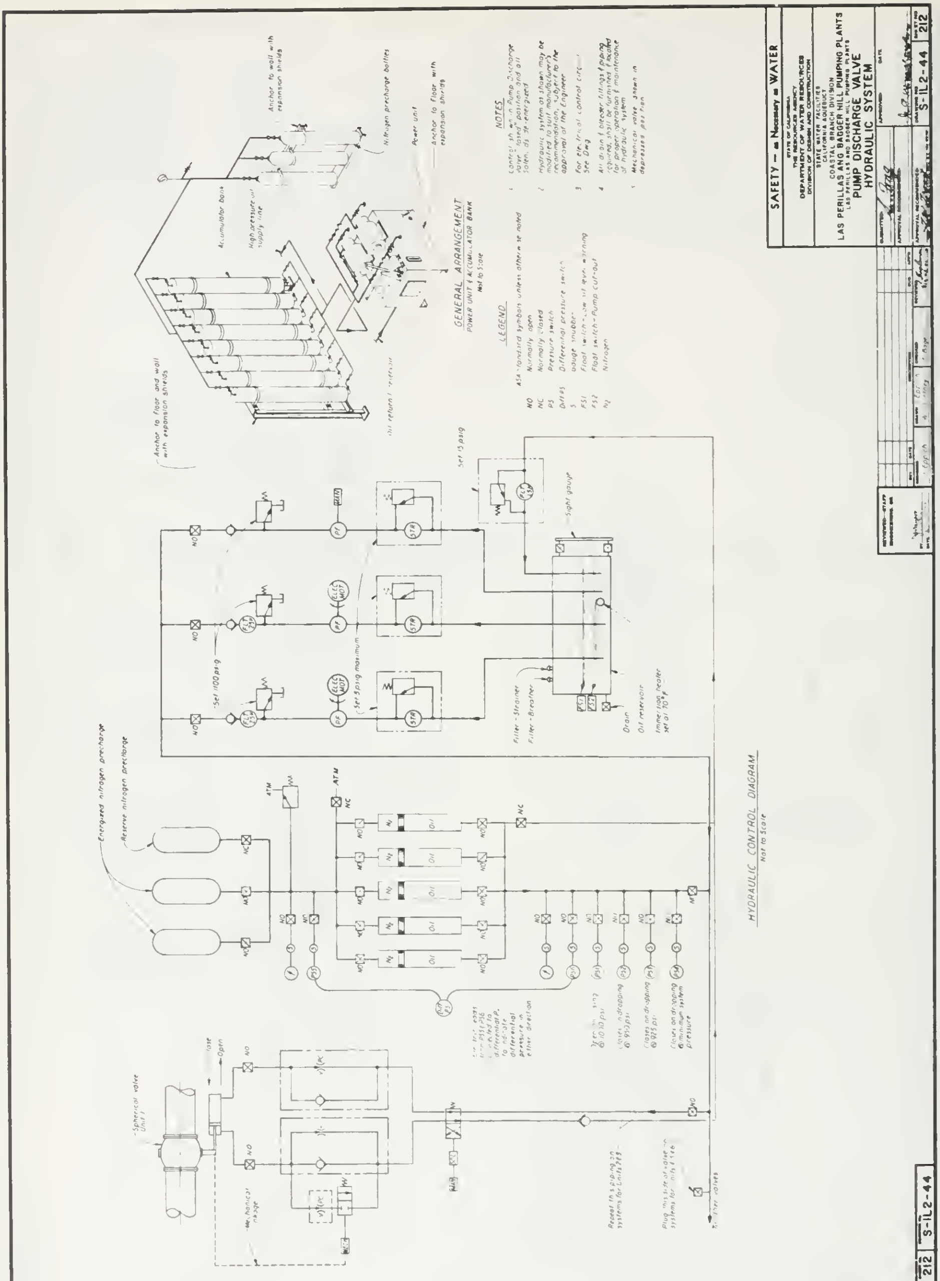

Figure 410. Pump Discharge Valve—Hydraulic System

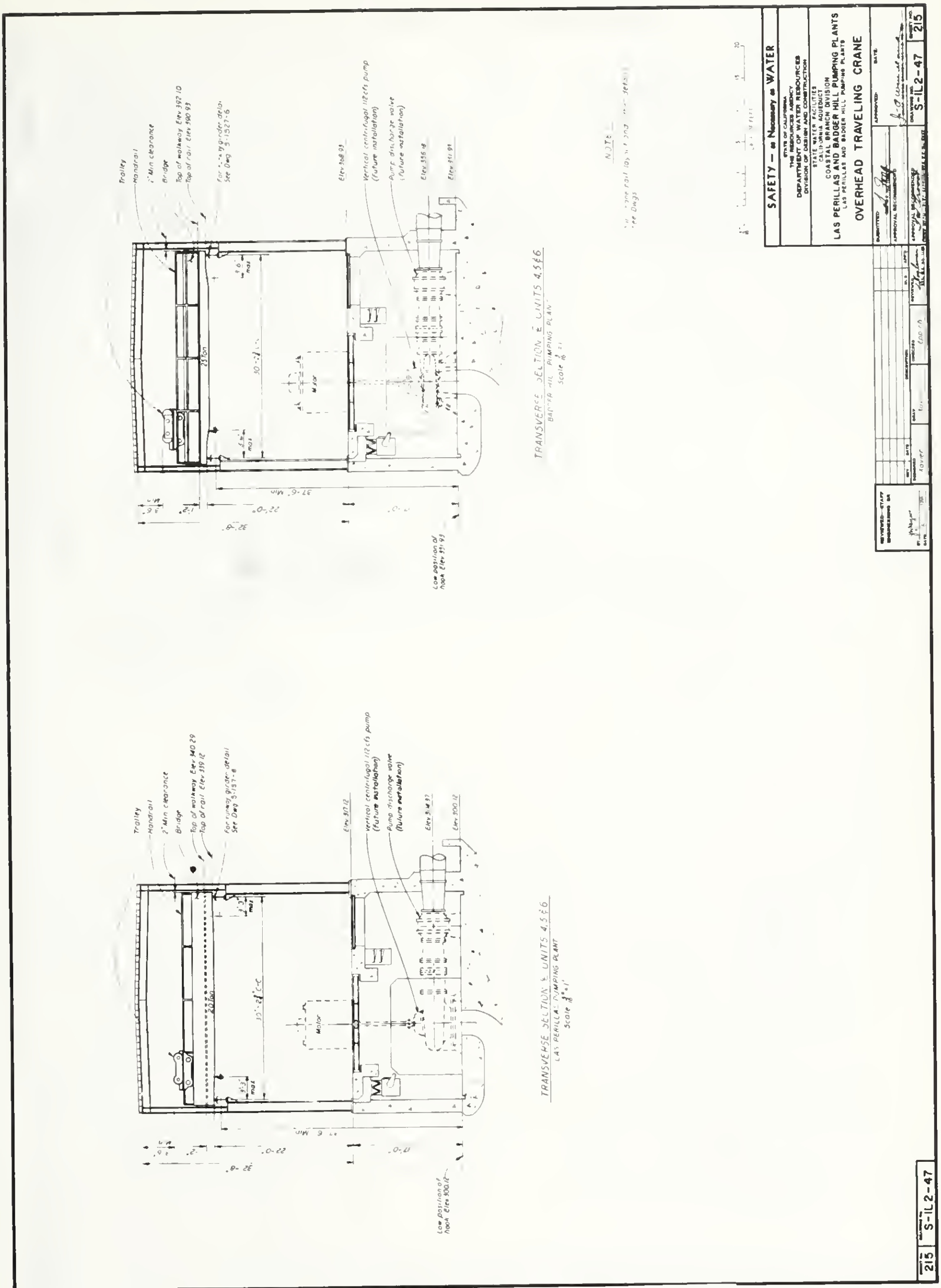

Figure 411. Overhead Traveling Crane

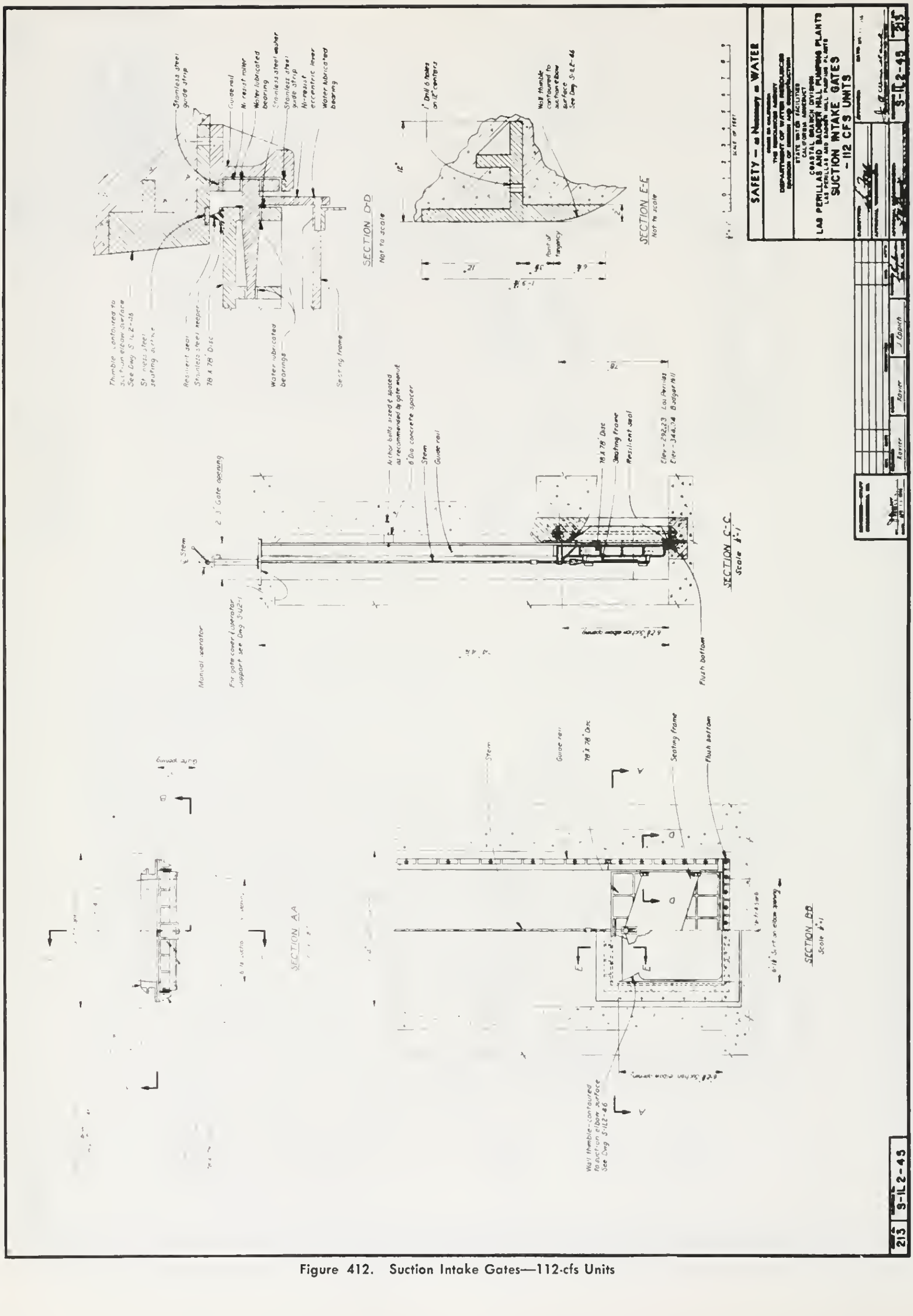

Figure 412. Suction Intake Gates—112-cfs Units

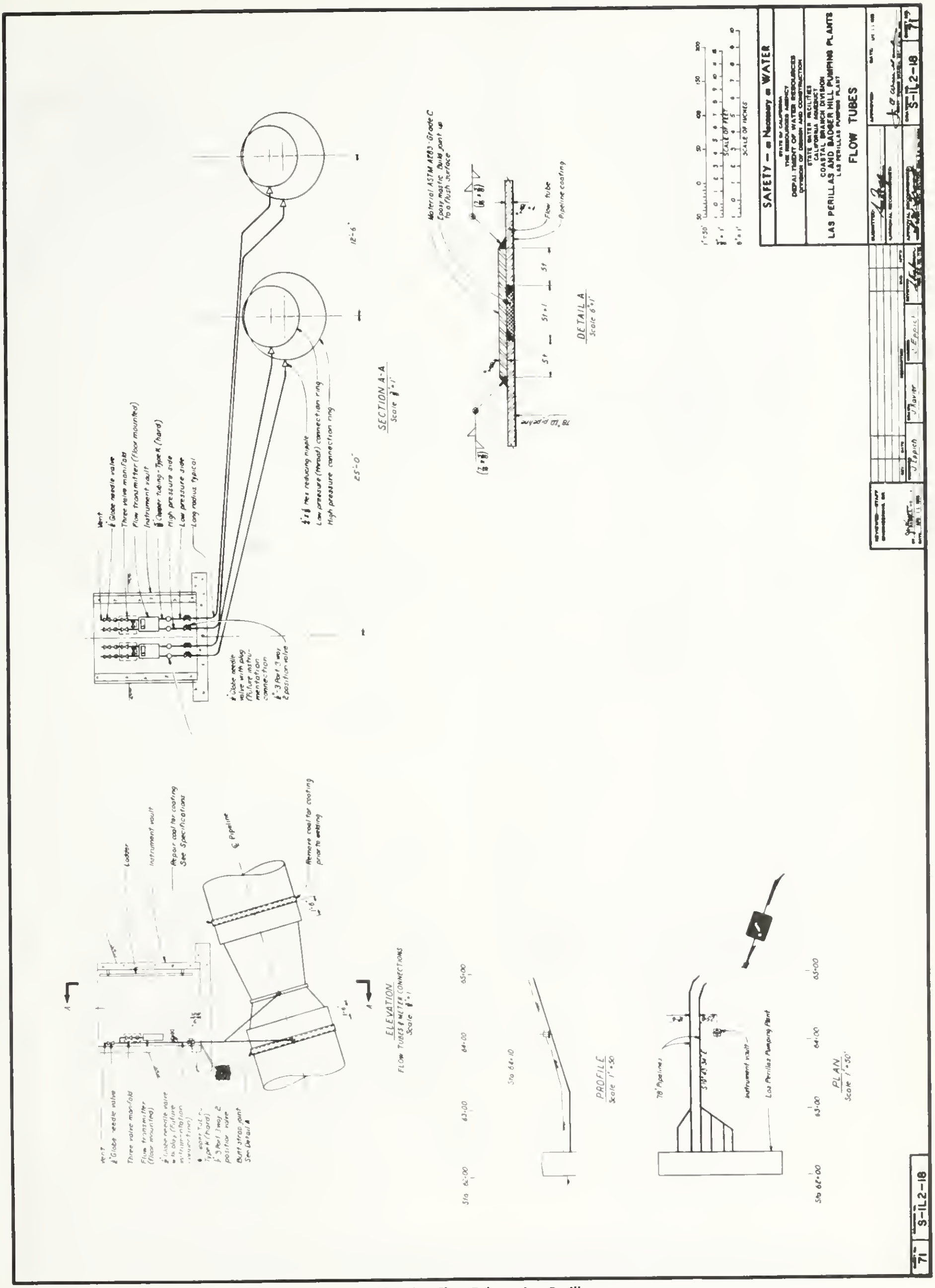

Figure 413. Flaw Tubes—Las Perillas

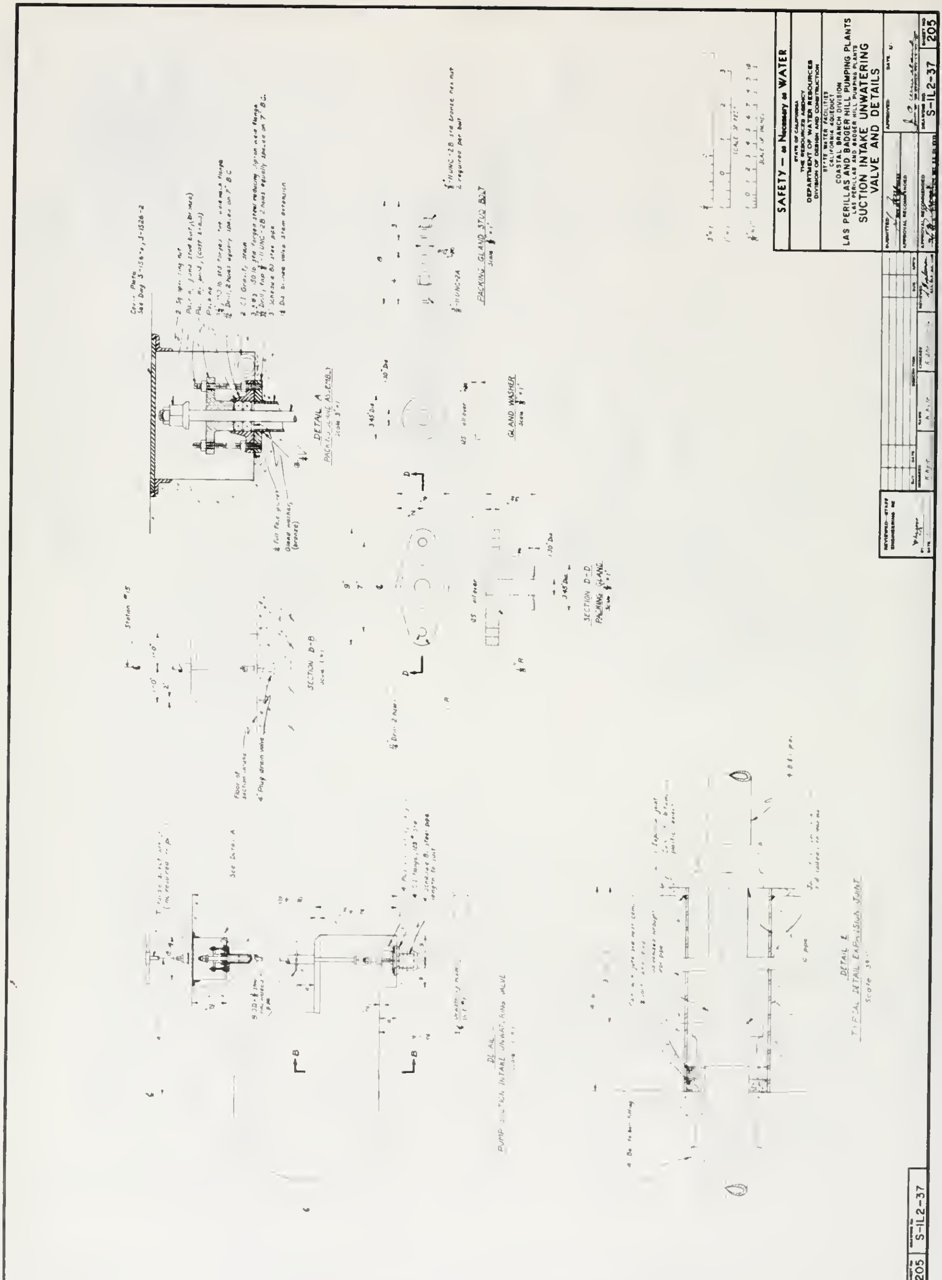

Figure 414. Suction Intake Dewatering Valve

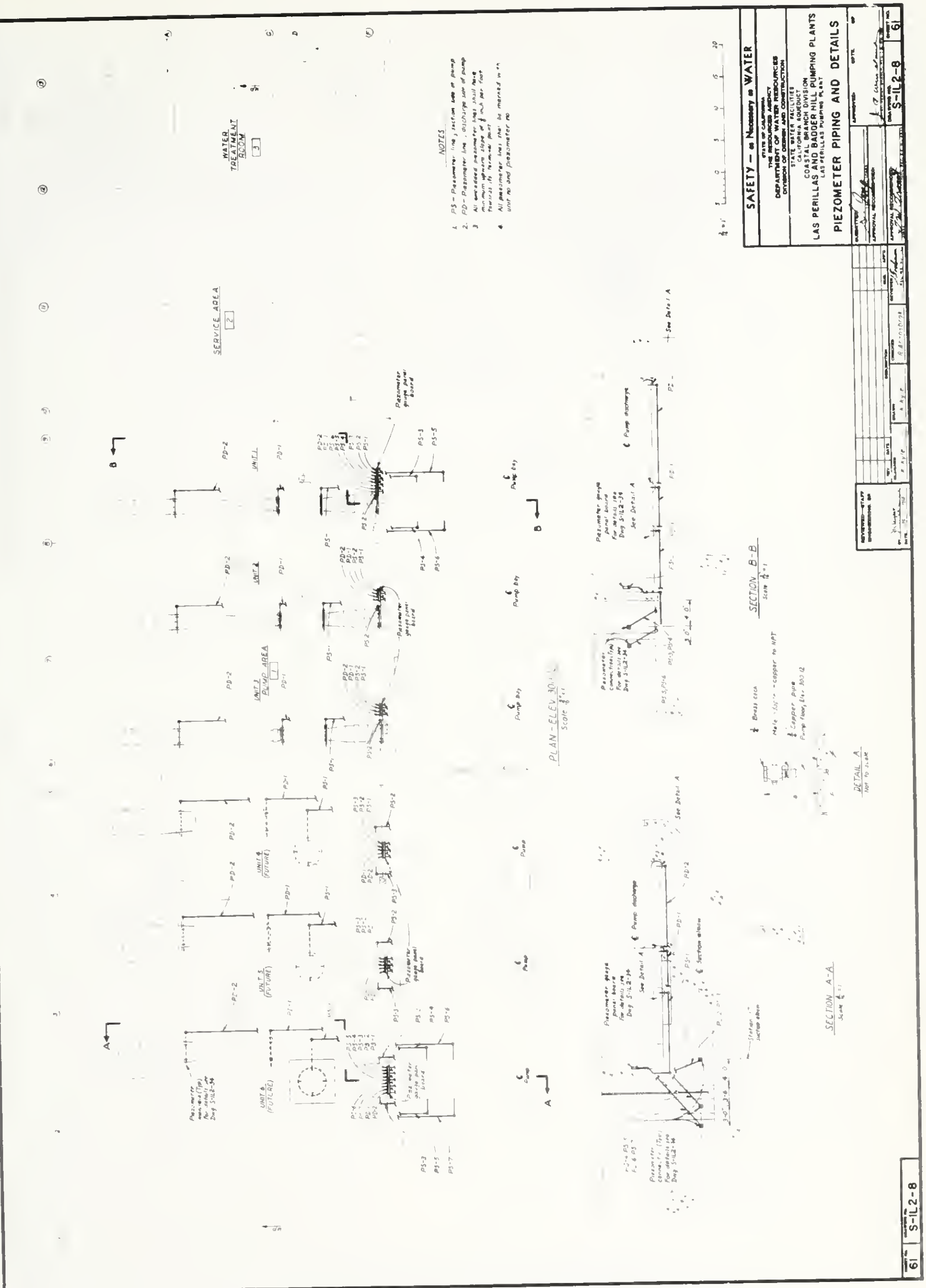

Figure 415. Piezometer Piping—Las Perillas

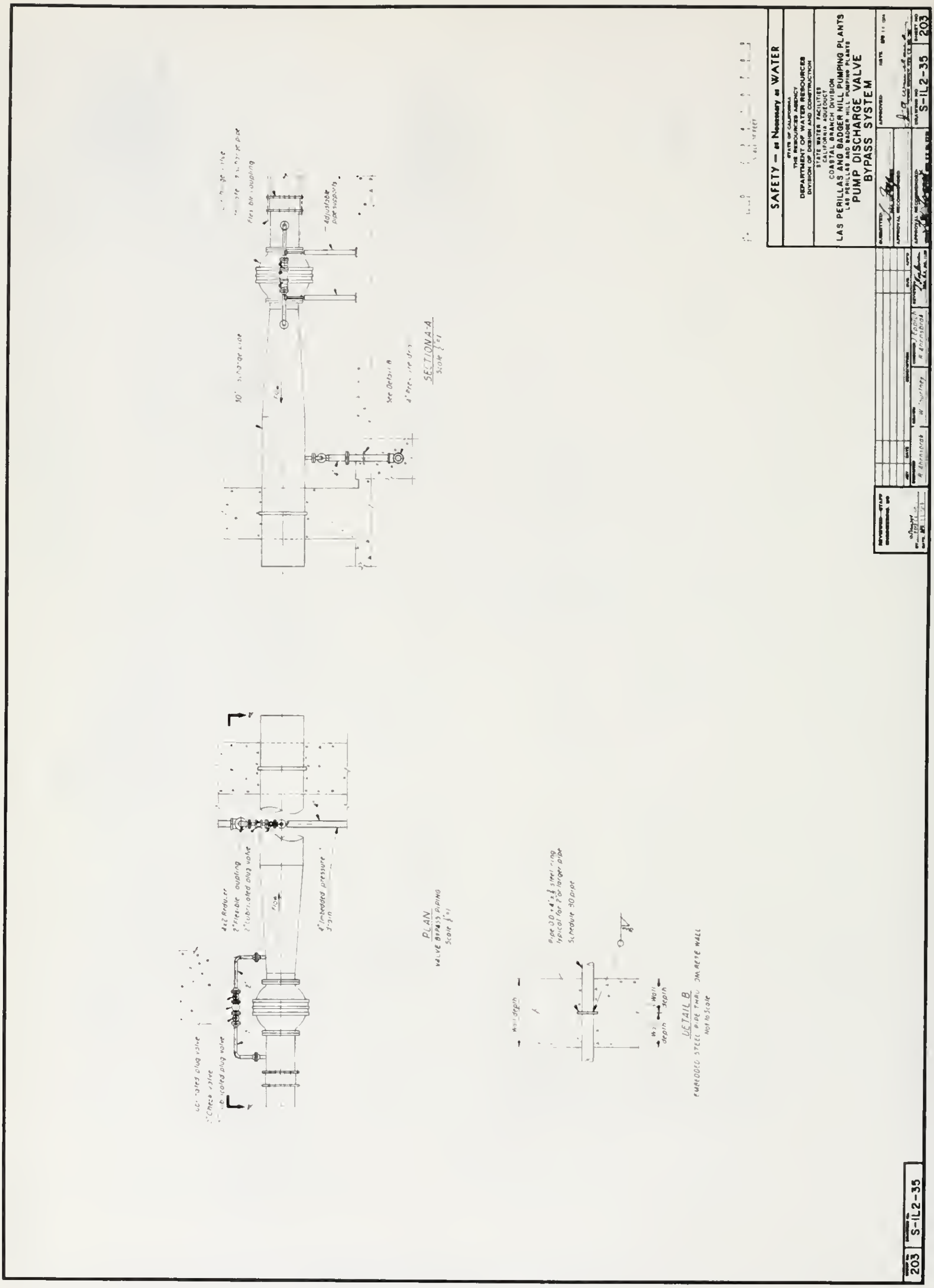

Figure 416. Pump Discharge Valve—Bypass System

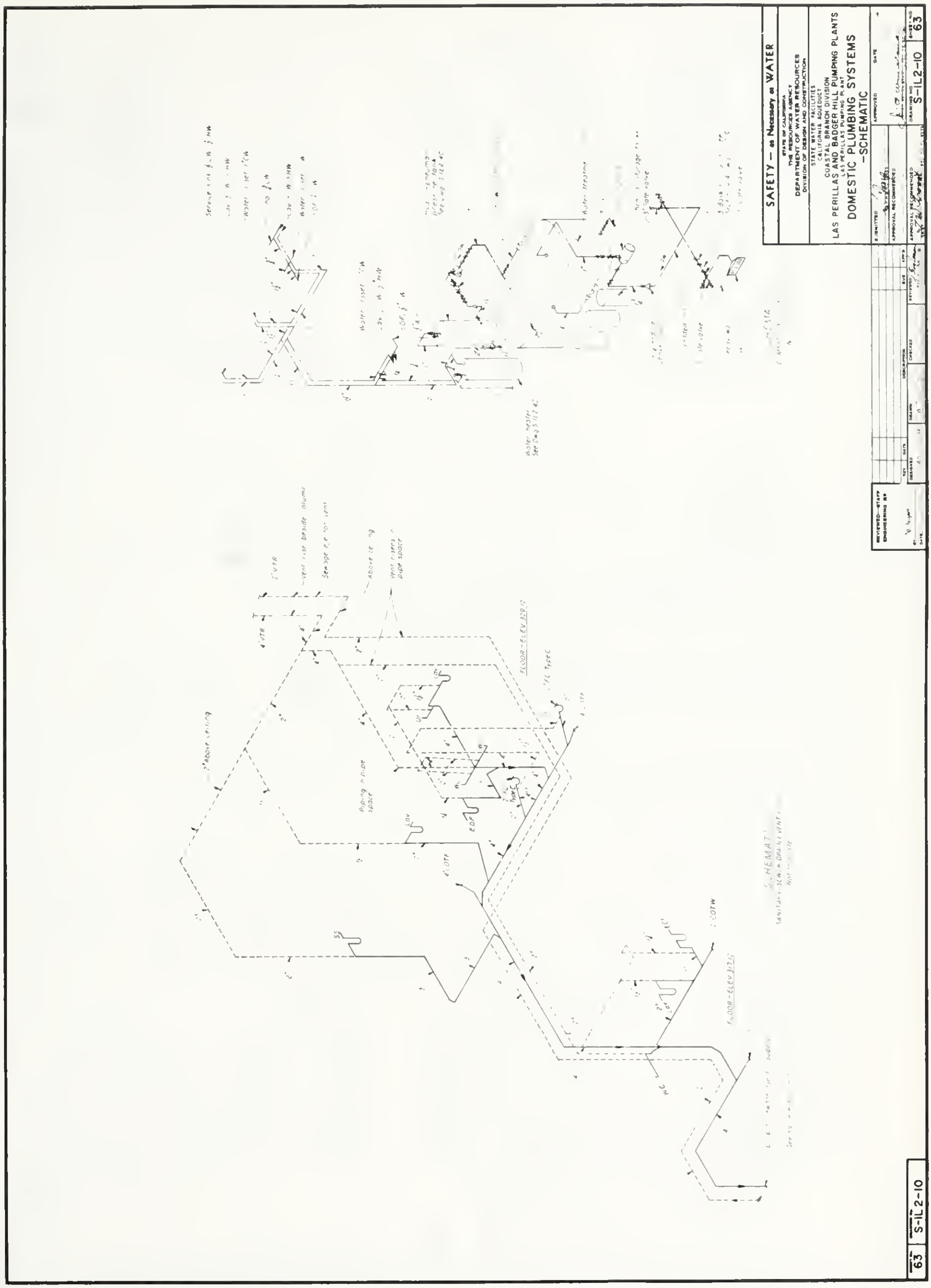

Figure 417. Domestic Plumbing Systems—Las Perillas

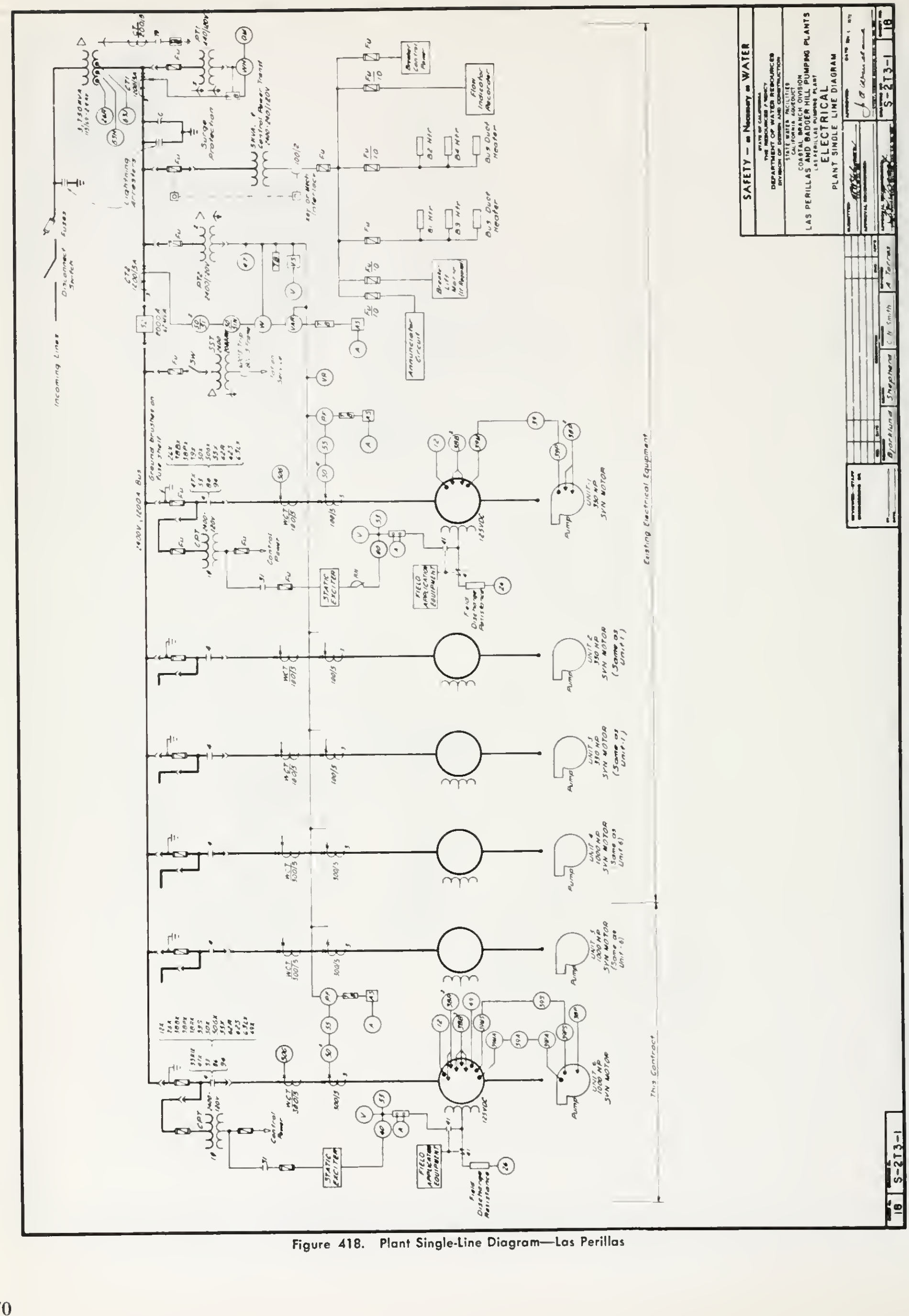

Figure 418. Plant Single-Line Diagram—Las Perillas

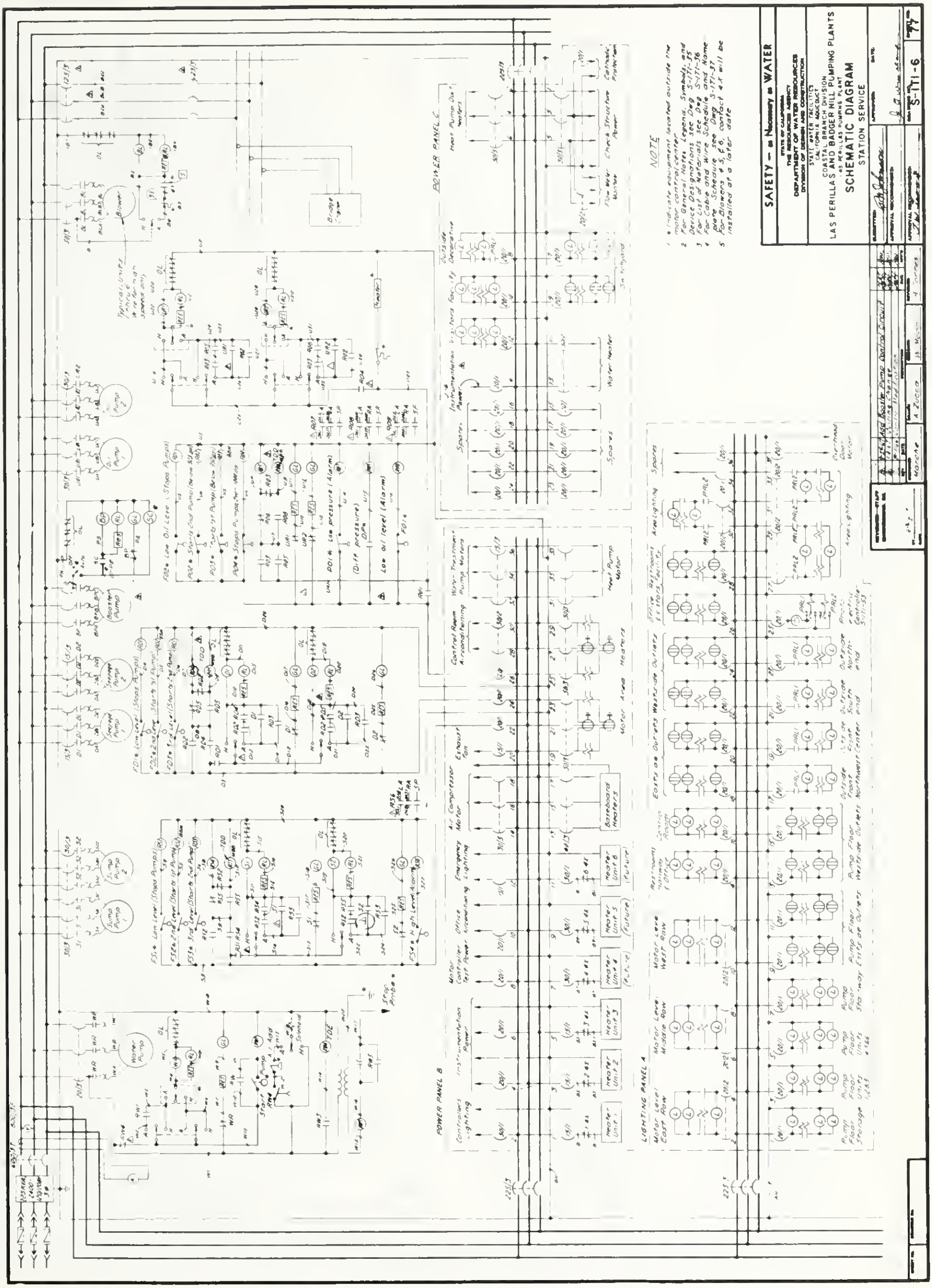

Figure 419. Station Service Schematic—Las Perillas

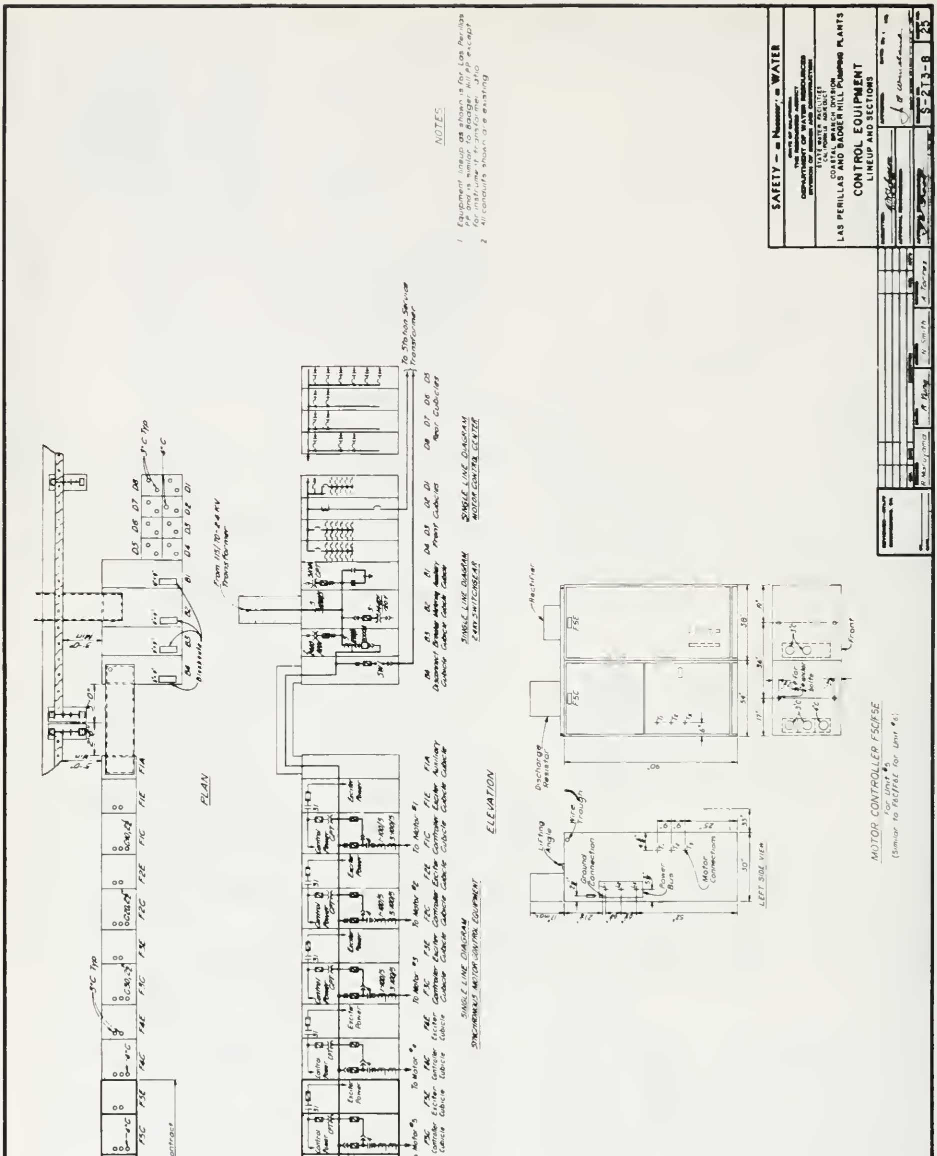

Figure 420. Control Equipment—Lineup

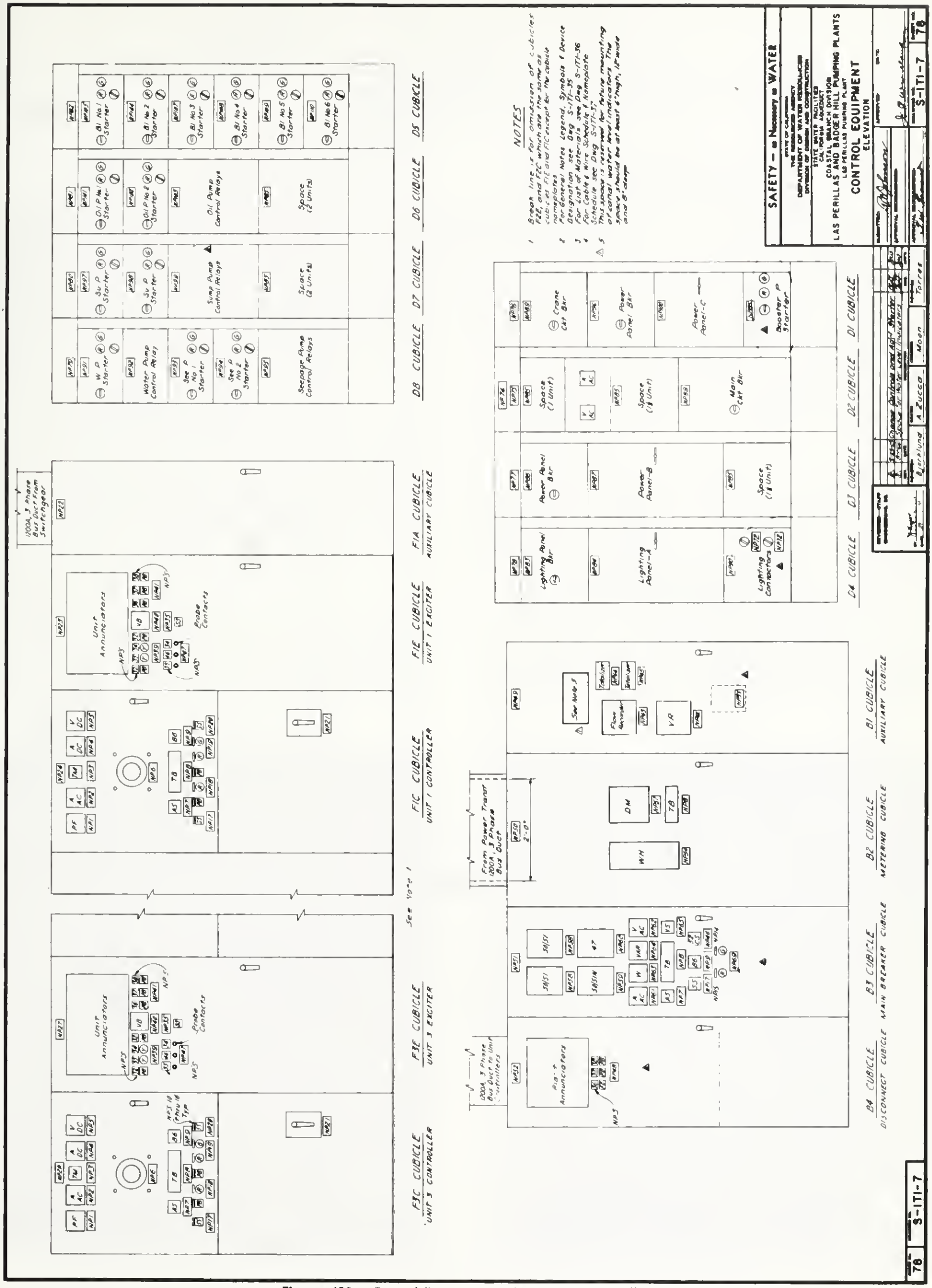

Figure 421. Control Equipment—Elevotion—Las Perillas

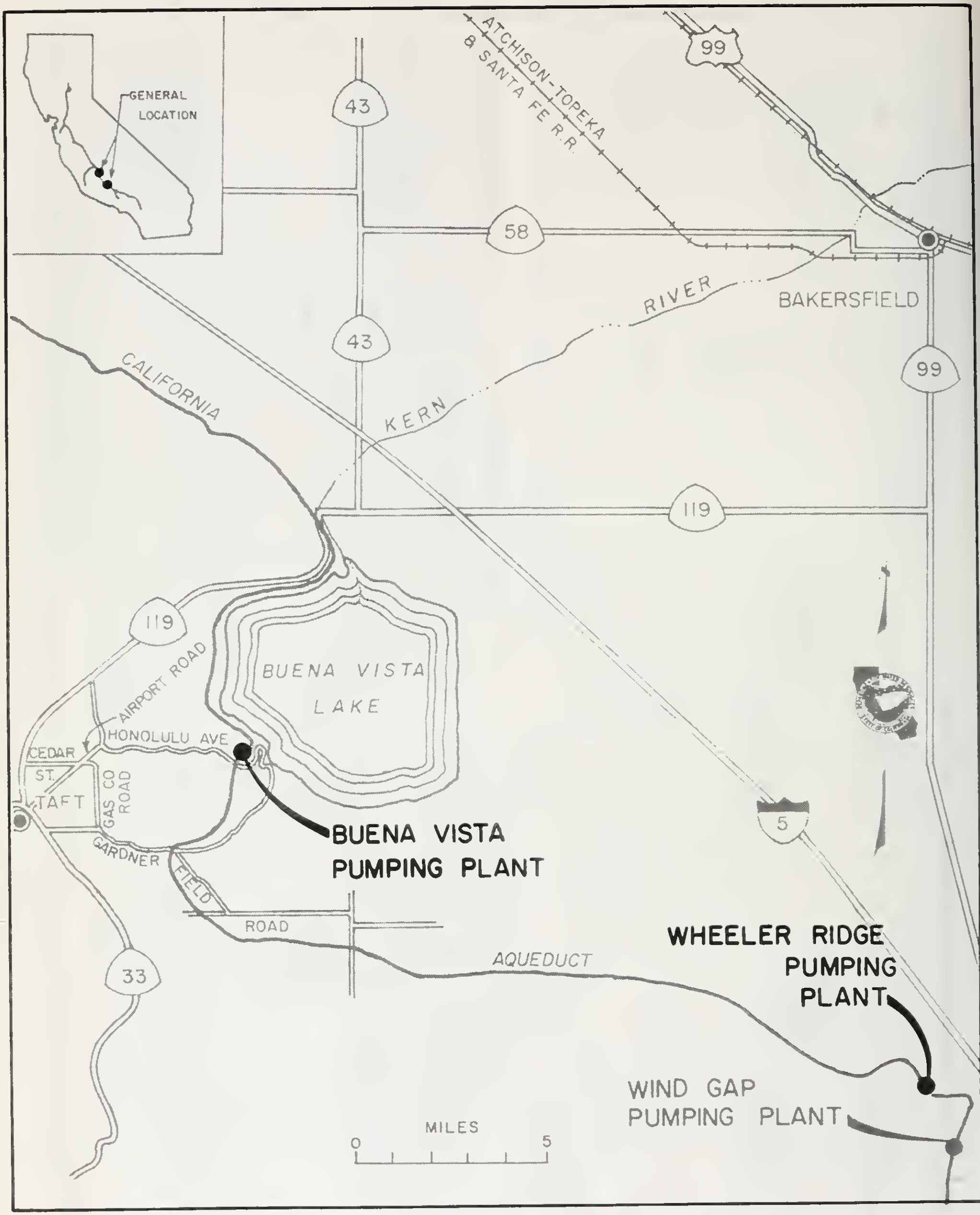

Figure 422. Location Map—Buena Vista and Wheeler Ridge Pumping Plants

CHAPTER XI. BUENA VISTA AND WHEELER RIDGE PUMPING PLANTS

General

Location

Buena Vista Pumping Plant, constructed during the period from 1967–1972, is located on the California Aqueduct approximately 24 miles southwest of Bakersfield in Kern County (Figure 422). Access to this pumping plant is by an extension of Lake Station Road from Gardner Field Road, approximately 7 miles east of Taft, California.

Wheeler Ridge Pumping Plant, also constructed during the period from 1967–1972, is located approximately 27 miles downstream from the Buena Vista Pumping Plant about 23 miles south of Bakersfield, Kern County, on the west side of U.S. Highway 99 (Figure 422). Access to this pumping plant is by a road that connects to Maricopa Road (State Highway 166).

Purpose

Buena Vista Pumping Plant operates, in a series of sequential lifts in the southern San Joaquin Valley, with Wheeler Ridge, Wind Gap, and A. D. Edmonston Pumping Plants conveying California Aqueduct water to and across the Tehachapi Mountains. Delta Pumping Plant and Dos Amigos Pumping Plant, upstream from this series of plants, are described in Chapters IV and IX of this volume. In this series, Buena Vista Pumping Plant provides the first lift, from elevation 295.4 feet to elevation 500.6 feet. It also furnishes water for turnouts in the reach of aqueduct extending beyond to Wheeler Ridge Pumping Plant.

Wheeler Ridge Pumping Plant provides the next lift from elevation 492.0 feet to elevation 724.5 feet and furnishes water for a turnout in the reach of aqueduct extending beyond to Wind Gap Pumping Plant.

Description

Buena Vista and Wheeler Ridge Pumping Plants basically are similar in design and configuration (Figures 423 and 424). Results and conclusions of preliminary studies and design for Buena Vista were equally valid for Wheeler Ridge and therefore were used for both plants. Both plants have reinforced-concrete substructures, structural-steel superstructures, switchyards, transformer yards, exposed steel discharge lines, and siphon outlet facilities. All pumping units consist of vertical-shaft, single-stage, centrifugal-type pumps directly connected to vertical synchronous motors.

Figure 423. Aerial View—Buena Vista Pumping Plant

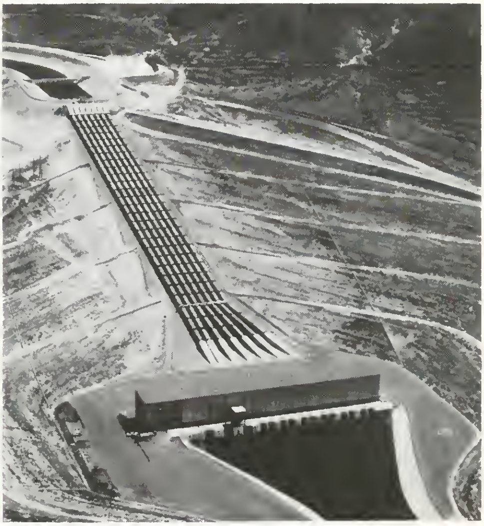

Figure 424. Aerial View—Wheeler Ridge Pumping Plant

Buena Vista Pumping plant has ten pumping units (Figure 425) with a total design flow of 5,365 cubic feet per second (cfs). Seven of the pumping units are rated 17,000 horsepower (hp), 631 cfs (each), 257 rpm, at 209 feet of head and each of the remaining three units is rated 8,500 hp, 316 cfs at 360 rpm, and 209 feet of head. Each of the 316-cfs units discharges through a 66-inch butterfly valve and a manifold to a common 9-foot discharge line. Each of the 631-cfs units discharges through a 90-inch butterfly valve into an individual 9-foot discharge line.

Wheeler Ridge Pumping Plant has nine pumping units with a total design flow of 4,926 cfs. Six of the pumping units are rated 20,000 hp, 657 cfs (each), 277 rpm, at 238 feet of head and each of the remaining three units is rated at 10,000 hp, 328 cfs at 400 rpm, and 238 feet of head. Similar to Buena Vista, each of the small units discharges through a 66-inch butterfly valve, and a manifold to a common 9-foot discharge line and the large units discharge through 90-inch butterfly valves into individual 9-foot discharge lines.

Representative drawings are included at the end of this chapter.

Geology—Buena Vista

Areal Geology

Buena Vista Pumping plant is in the folded continental sediments of the Buena Vista Hills on the northeast flank of the southeasterly plunging Buena Vista anticline. Two geologic units, Tulare formation and Recent lake sediments, make up the thick continental deposits.

Site Geology

During excavation of the Recent lake sediments, 65 to 70% of the material encountered was a poorly consolidated silty sand. The 25 to 30% of clay and claystone encountered was jointed and folded. The majority of the joints have been filled or healed with gypsum. Excavation extended into the Tulare formation and encountered 55 to 60% poorly consolidated sand and silty sand with approximately 40 to 45% stiff clay, or claystone, interbedded with thin layers of silty sand and sandy silt.

Figure 425. Interior View of Motor Floor—Bueno Vista

Geologic structure of the intake channel consists of clays, silts, and sand layers in small folds on the limbs of a larger anticline and syncline. Folds are asymmetrical and the anticline is overturned.

Potentially expansive clays, gypsite, and organic rich soils exposed in the intake channel were unsuitable as foundations for concrete canal linings. This material was overexcavated and replaced with a compacted sublining.

Pumping plant bowl excavation exposed numerous faults and expansive clays in the foundation. The foundation was covered with air-blown mortar to prevent desiccation of the clays and provide a working surface during construction.

Geologic Exploration

Design exploration included large-diameter holes accommodating a man-cage, rotary core holes, trenches, electrical conductivity surveys, seismic surveys, and a ground water investigation. Geologic mapping and slope inspection proceeded as the excavation advanced.

Instrumentation

Rebound Gauges. A total of 20 rebound gauges were installed in the foundation area. Because some damage or loss of gauges usually occurs during construction, a balanced distribution of both the cased gauges and buried gauges was utilized. Rebound gauges were surveyed regularly during excavation.

During excavation in the bowl area, the foundation rebounded an average of 0.32 of a foot with approximately 3,200,000 cubic yards of material removed. The rate of rebound accelerated rapidly to an average cumulative total of 1.51 feet after approximately 4,300,000 cubic yards of material was removed. Average cumulative rebound recorded after the first stage of excavation was 1.71 feet with a maximum reading of 2.62 feet recorded by one gauge.

Unusual cracking was noted on the west side of the excavation. Thrust and tension cracks developed, suggesting overthrusting from the west. Exposure of the underlying clay in the southwest corner revealed the clay had bulged up as if pushed from beneath.

Final structural excavation was done in three stages to ensure minimum unloading and the fastest possible reloading of the foundation and manifold areas. The first stage of final excavation was on the east end. The rate of rebound accelerated rapidly until the first stage was completed and mass concrete placement begun. Rebound continued after completion of the first stage and during the second-stage excavation.

During the third and final stage on the west end, the rate of rebound again increased. Generally, the rebound was concentrated in the west end with a slight settlement noted on the east end as concrete placement began reloading the foundation. As the final stage neared completion, horizontal movement, as much as $\frac{1}{2}$ inch to the northeast, occurred approximately 7 feet below the contact of the sand and clay beds. Movement was along a slickensided bedding plane at the west end. Minor cracking was noted around the foundation excavation.

Slope Indicator. Fifteen slope-indicator casings were installed in the plant area to monitor slope stability. Measurements indicated two characteristic types of deflections: a sequence of sharp offsets at various depths, and a gradual tilt from top to bottom. Analysis disclosed that horizontal movements at Buena Vista Pumping Plant were caused directly by differential vertical movements, and the vertical movements resulted from deep-seated rebound following load removal over a large area.

Ground Water

Ground water was encountered near an invert level of 274.2 feet during the intake channel excavation. The aquifer was a medium to coarse sand and silty sand with occasional thin gravel lenses, approximately 30 to 40 feet thick. A sump was dug and a portable pump was used to lower the static water level below invert elevation. Prior to trimming and lining, an underdrain system was installed beneath the invert. The system drained to a sump installed on the right side of the prism section.

Artesian pressures existed in the pumping plant bowl area. A temporary ground water pumping system was installed to lower pressures prior to and during the final structural excavation. The system consisted of five pumping wells, five observation wells, and one discharge line.

The artesian aquifer on the west side of the plant was effectively depressurized, with water levels lowered below the confining layer. Water levels on the east side of the plant were lowered only 3 feet. Drawdown on the east side was apparently affected by the low permeability zone related to a fault which crosses the excavation.

Seismicity

Numerous faults were exposed by the excavation. There is no direct evidence that indicates faults exposed in the pumping plant bowl are active or will affect the stability of the plant. Two slope-indicator casings were installed on the 460-foot-elevation berm to monitor a thrust fault exposed above and below the 420-foot-elevation berm. No fault movement was recorded. Additional shear zones that extend short distances and show minor displacement gave no evidence of recent movement.

Geology—Wheeler Ridge

Areal Geology

Wheeler Ridge Pumping Plant site is near the base of the Wheeler Ridge anticline, a part of the San Emigdio Mountains. Wheeler Ridge is a complex structure of intensely folded and faulted, consolidated, sedimentary deposits of Tertiary Age. A combination of sedimentary rock, steep gradients, high-intensity runoff, and sparse vegetation has resulted in the erosion of deep gullies and the formation of large coalescing alluvial fans.

Site Geology

The plant is constructed on the northern flank of Wheeler Ridge, an asymmetrical anticline plunging both east and west with a steep northeastern dip. Flanking Wheeler Ridge at the Wheeler Ridge thrust fault are coalescing Recent alluvial fans that overlay the Tertiary Tulare formation. Alluvial fans are nearly flat-lying deposits of sandy clay and silty sand with lenses of poorly graded sand and gravel. These deposits are a result of erosion of the Wheeler Ridge anticline. Tulare formation is a consolidated, interbedded, silty sand, silty-gravelly sand, silt, and clay, intensely folded and faulted.

The plant is 2,000 feet northwest of the surface-projected intersection of the Wheeler Ridge thrust fault and White Wolf fault. The discharge lines cross the projected trace of the White Wolf fault. The Aqueduct to Wind Gap Pumping Plant is approximately parallel to the Wheeler Ridge thrust fault.

Geologic Exploration

A 48-inch-diameter 197-foot-deep hole was drilled in the plant bowl area for inspection of the material from a man-cage. Plate bearing tests were conducted at 10-foot intervals and in-place samples were taken. Design exploration also included rotary and auger drill holes, with electric logging of drill holes in the plant bowl to determine the ground water table.

Instrumentation

Slope indicators and rebound gauges were installed and monitored during excavation. No significant movement was noted. Two tiltmeters were installed in the area to measure tilting resulting from tectonic movement, deep subsidence, or shallow subsidence. A slight tilting was recorded.

Seismicity

Wheeler Ridge is in an area of major seismic activity. White Wolf fault and Wheeler Ridge thrust fault are within 2,000 feet of the plant. Epicenter of the 1952 movement on the White Wolf fault (7.7 Richter magnitude) was in the vicinity of Wheeler Ridge. Seismic approval of the plant site was made by the Consulting Board for Earthquake Analysis in a written communication to the Department of Water Resources May 27, 1964, stating "Although there are many faults in the area, we consider it unlikely that there will be any significant fault displacement during the life of the structure".

Civil Features

Preliminary Studies

Preliminary work for both plants consisted of optimization studies involving size, number of pumping units, and space requirements. In the initial studies, simple horizontal intake suction elbows were considered. However, on the basis of economic studies and the requirements of plant stability under earthquake conditions, 135-degree suction elbows were adopted, setting the structures deeper in the ground, thus providing the necessary stability.

One of the major design problems was the Buena Vista Pumping Plant foundation rebound. The plant is located in a bowl that initially was excavated as a part of the intake channel under an earlier contract. The final excavation was completed under the plant construction contract. As discussed previously in this chapter, rebound of the foundation was expected, since the material underlying the plant consisted of interbedded sands and expansive clays subjected to artesian water. This rebound was considerably greater than originally anticipated and amounted to an average of 1.7 feet. Staged excavation and construction were specified in the plant contract to minimize and control foundation unloading. Monoliths of the plant substructure also were keyed to prevent differential movement.

Wheeler Ridge Pumping Plant is founded on poorly consolidated alluvial deposits consisting of gravelly silty to clayey sands. Primary concern was foundation tilting. Repeated levelings over bench marks in the immediate area suggested that a differential tilt of about .01 foot per 100 feet per year may occur during the life of the plant. Monoliths of Wheeler Ridge Pumping Plant also were keyed to prevent differential movement.

Site Development

The initial site development for Buena Vista and Wheeler Ridge Pumping Plants involved excavations for the plant bowls, intake canals, and discharge lines. At Buena Vista Pumping Plant, the bowl excavation is approximately 610 feet wide, 680 feet long at the main floor elevation of the plant, and 150 feet deep. Cut slopes in the main bowl are 2½:1 with 20-foot-wide benches at approximately 40-foot vertical intervals. At Wheeler Ridge Pumping Plant, the bowl excavation is approximately 640 feet wide and 600 feet long. Average depth of bowl excavation is 120 feet. Cut slopes in the bowl are 3:1 with 20-foot-wide benches at approximately 40-foot intervals vertically.

Runoff from the surrounding area of both plants is prevented from entering the bowls by cutoff ditches and protective dikes. Rainfall in the bowls is collected by slope drains which carry it to the plant yard level and ultimately to the plant forebay.

Plant Structures

Both Buena Vista and Wheeler Ridge Pumping Plants have four pump bays and a service bay. Each bay is a structurally independent monolith separated from adjoining bays by expansion joints. Buena Vista Pumping Plant is 435 feet - 8 inches long, and Wheeler Ridge Pumping Plant is 408 feet - 8 inches long. The substructure and superstructure of both plants are 124 feet and 59 feet - 6 inches wide, respectively; the height from centerline of distributor to the motor floor is 26 feet - 6 inches and from the motor floor to the top of the crane rail is 32 feet - 11 inches. The general shape of the lower portion of the pump bay substructures was governed by the 135-degree suction elbow. Size of pump bays and service bays was based on space requirements of pumps, motors, and auxiliary equipment.

The basic elements of the superstructures are rigid steel frames which support the upper portion of the buildings and the bridge cranes. The lower 8 feet of the exterior walls are reinforced-concrete block, and the upper portion is metal sandwich panels. The roofs are composition surfaces laid on diaphragms of No. 16-gauge T-decking. The architectural motif described in Volume VI of this bulletin was used at both plants.

Waterways

Intakes for Buena Vista and Wheeler Ridge Pumping Plants are of standard configuration, which required flaring of the Aqueduct to form the intake transitions. Installed waterway equipment includes trashracks and steel bulkhead gates on the intake side of the plant, pumps and discharge valves inside the plant, and siphon outlet facilities at the outlet of the discharge lines.

Intake Facilities. The concrete-lined intake channels are trapezoidal in cross section, have a 24-foot bottom width, a water depth of 22 feet, and side slopes of 2:1. The inverts slope .000040 and .000045 at Buena Vista and Wheeler Ridge Pumping Plants, respectively.

Trashracks are provided for each pump intake to prevent the passage of debris. They are cleaned by mechanical rakes operated by 10-ton gantry cranes mounted on the decks of the plant structures.

Structural-steel bulkhead gates are provided for closure of the pump intakes. They operate in slots formed in the piers at the wall of the plant structure. Bulkhead gates are handled by the 10-ton gantry cranes and, when not in use, are stored in gate storage vaults at the end of each plant.

Pump Discharge Lines. The Buena Vista Pumping Plant and Wheeler Ridge Pumping Plant discharge lines are virtually identical in concept and design. They differ only in design head, length, number of lines, and slopes as follows:

	Buena Vista	Wheeler Ridge
Static Head—feet	205	233
Dynamic Head—feet	209	238
Distance—Valves to Siphon—feet	887	1,466
Number of Lines	8	7
Slope—%	33	19
Design Head at Manifolds—feet (includes upsurge)	303	362

All discharge lines are 9-foot-diameter steel pipes, supported by ring girders resting on concrete piers spaced at 40-foot intervals, using sleeve-type couplings to connect adjacent pipe sections. The main components of the system include manifolds and encased pipes, main discharge lines, and siphon outlets.

Manifolds and Encased Pipes. The manifold sections and encased pipes extend from the discharge valves to the end of the concrete encasement and include valve tapers, articulation sections, wye branches, and concrete-encased pipes.

Articulation between each valve taper and the manifold, as described in Chapter I of this volume, is provided by the use of a short pipe section, approximately one pipe diameter in length, supported between a pair of special, extra-long, sleeve-type couplings.

Downstream from the articulation sections in both plants, the piping from Pump Units Nos. 1, 2, and 3 is manifolded (Figure 426). The 60-degree wye branches are the three-stiffener-ring type and are not symmetrical. The junction for Units Nos. 1 and 2 has both an internal splitter plate and external reinforcing. The remaining junction has external reinforcing only. Steel used for the manifold pipes is ASTM A285, Grade C, firebox quality. Shell plates are $\frac{9}{16}$ of an inch thick, crotch plates are 1 inch thick, and reinforcing plates either 1 inch or $1\frac{1}{2}$ inches in thickness. Pipes from the remaining pump units have a $\frac{9}{16}$-inch wall thickness and are not manifolded.

Figure 426. Manifold—Wheeler Ridge

All portions of the discharge lines under the pumping plant backfill are encased in reinforced concrete. This concrete encasement supports the earth load and acts as an anchorage resisting the thrusts developed at the bends and wye branches. Encasement is described in Chapter I of this volume.

Main Discharge Lines. Steel used in the main discharge lines is ASTM A285, Grade C, firebox quality, with the shell thickness varying from $\frac{5}{16}$ of an inch to $\frac{9}{16}$ of an inch.

Because both plants are located in seismically active areas, which are also subject to deep subsidence and tectonic tilting, requirements for articulation are the most stringent on the entire California Aqueduct. The design criteria for the discharge lines required concrete piers at 40-foot intervals and a support system which would allow 6 inches of transverse displacement between adjacent piers without overstressing the fixed support ring girder columns or placing large shear loads across the sleeve-type couplings.

To enhance the overall stability of the discharge line system, the center set of support piers at Buena Vista and the three suppport pier sets located at the quarter points between the bend anchors at Wheeler Ridge are supported on pairs of 30-inch-diameter cast-in-drilled-hole piles.

The main discharge line system consists of typical ring girders; a beam and trunnion assembly attached to the girder column bearing plates at the fixed supports; neoprene bearing pads, located between bearing plates and support piers; and sleeve-type couplings, which connect adjacent pipe sections.

The special ring girder support system is unique, as compared to a conventional ring girder pipe support system. In the conventional system, each section of pipe is supported by a fixed bearing under each ring girder column, or leg, on the downhill end and a sliding bearing or rocker under each column on the uphill end. At each pipe joint, pairs of fixed and sliding bearings rest on a single concrete pier. Fixed bearings are bolted directly to the support pier, and sliding bearings allow longitudinal movement. With this type of system, the rigidity of the fixed-end support will not allow any transverse displacement between adjacent concrete piers without damaging the support system.

In the special ring girder support system used at Buena Vista and Wheeler Ridge Pumping Plants, all ring girder column bearing plates rest on $1\frac{1}{2}$-inch-thick neoprene pads which transfer loads perpendicular to the bearing plates onto concrete support piers. At each fixed support, loads parallel to the bearing plates are transferred to the support pier through a beam and trunnion pivot. The beam is a W18X45

(18WF45) section, mounted flat and welded to the fixed support bearing plates, and has a reinforced hole through the midpoint of the web. The trunnion is a 3-inch-diameter steel pin, embedded in the concrete support pier, which protrudes through the hole in the beam to form the pivot. It is the forcing of rotation around this pivot, combined with the flexibility afforded by the neoprene pads, which allows transverse pier displacement to occur.

Both plants have small anchors at the upper end of the discharge lines to resist thrust forces caused by the bends. Wheeler Ridge discharge lines also have an additional anchor at horizontal bends, approximately 400 feet beyond the Pumping Plant. The anchors on the exposed portions of both plants are single structures which tie all lines together.

Stiffener rings on exposed sections of the discharge lines modify the resonant frequency of the pipe sections, thus eliminating the possibility of vibrations caused by pump pulsations. Because the small and large pumps are not identical in rotational speed and number of pump impeller vanes, the stiffener spacing on discharge line No. 1 is different from the spacing on the remainder of the discharge lines.

Siphon Outlets. The siphon outlet structures are typical, steel-lined, reinforced-concrete structures (see detailed description in Chapter I of this volume). The Buena Vista siphon has eight bays; the Wheeler Ridge siphon has seven bays. Backflow into the discharge lines is prevented by the siphon breaker valves, which allow air to enter the siphon at the crest. Stoplogs are provided at the downstream end of each bay so that the siphons can be dewatered for maintenance.

Mechanical Features

General

The mechanical installation at Buena Vista Pumping Plant includes ten pumps with discharge valves, and at Wheeler Ridge Pumping Plant there are nine pumps, each with a discharge valve. Each plant also contains two equipment-handling cranes and auxiliary support equipment.

This chapter contains information and a description of the mechanical equipment for both Buena Vista and Wheeler Ridge Pumping Plants which are unique to these two plants. General information on mechanical equipment which is common to all plants of the State Water Project is discussed in Chapter I of this volume.

Pumps

The main pumps are vertical-shaft, single-stage, diffuser casing, centrifugal type, directly connected to synchronous motors. All pumps rotate counterclockwise as viewed from the motor end (Figures 427, 428, 429, and 430).

Equipment Ratings

Main Pumps—Buena Vista and Wheeler Ridge Pumping Plants
Manufacturer: Allis-Chalmers Manufacturing Co.
Type: Vertical-shaft, single-stage, centrifugal

Pumps Nos. 1, 2, and 3—Buena Vista Pumping Plant

Discharge, each:	316 cfs
Total Head:	209 feet
Speed:	360 rpm
Guaranteed Efficiency:	93.0%
Minimum Submergence at Pump Centerline:	15 feet

Pumps Nos. 4 through 10—Buena Vista Pumping Plant

Discharge, each:	631 cfs
Total Head:	209 feet
Speed:	257 rpm
Guaranteed Efficiency:	93.2%
Minimum Submergence at Pump Centerline:	15 feet

Pumps Nos. 1, 2, and 3—Wheeler Ridge Pumping Plant

Discharge, each:	328 cfs
Total Head:	238 feet
Speed:	400 rpm
Efficiency:	92.5%
Minimum Submergence at Pump Centerline:	10.5 feet

Pumps Nos. 4 through 9—Wheeler Ridge Pumping Plant

Discharge, each:	657 cfs
Total Head:	238 feet
Speed:	277 rpm
Efficiency:	93.0%
Minimum Submergence at Pump Centerline:	10.5 feet

Pump Discharge Valves (Both Plants)
Manufacturer: Yuba Manufacturing Division of Yuba Industries, Inc.
Type and Size— Units Nos. 1, 2, and 3—
66-inch, metal-seated, butterfly
Units Nos. 7 through 10—
90-inch, metal-seated, butterfly

Cranes (Both Plants)
60-Ton Bridge Crane
Manufacturer: Crane Hoist Engineering and Manufacturing Co.
Type: Overhead, traveling, bridge
10-Ton Gantry Crane
Manufacturer: Broadline Corp.
Type: Outdoor, traveling, gantry

Figure 427. Laboratory Testing of Model Pump

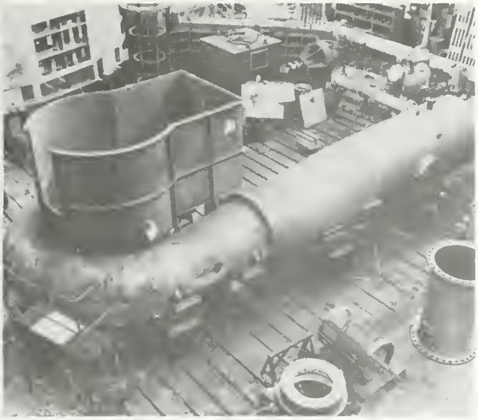

Figure 428. Shop Assembly of Pump

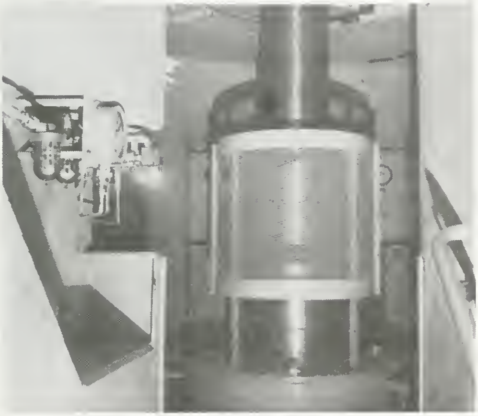

Figure 429. Pump Alcove

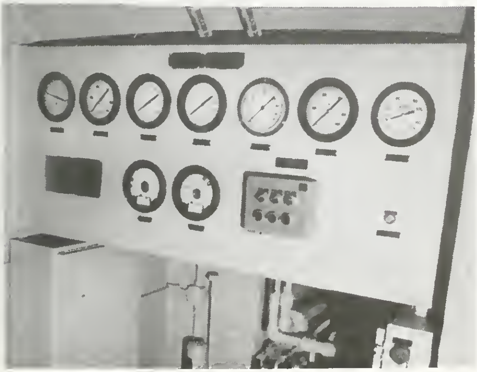

Figure 430. Gauge Board in Pump Alcove

The pump casings are embedded in the concrete substructure of the plant. All removable parts of the pump, including the impellers, shafts, guide bearings and housings, and top casing cover, are removable from above and designed to pass through the motor stator. Weight of the revolving parts and the hydraulic thrust are carried by thrust bearings in the motors.

Impellers are one-piece, enclosed, centrifugal, single-suction type, fabricated from cast steel and are provided with corrosion-resistant steel (modified AISI-422) wearing rings (Figure 431).

Removable and renewable wearing rings are located in the suction and casing covers opposite the wearing rings on the impeller crown and band and are made of AISI-422 stainless steel. The pump guide bearing is the self-lubricating skirt type.

Starting of the pumping units was based on depressing the water in the pump case below the impeller before closing the motor breaker and synchronizing to reduce the starting load on the motor. After synchronizing, the air in the pump case was bled off to allow the water to fill the case and to prime the pump before opening the pump discharge valve to progress into the pumping mode.

Utilizing this method resulted in violent lifting of the rotating parts when water in the pump case reached the impeller. Many field tests were made while investigating ways of eliminating this unacceptable condition. Before testing, however, a thrust collar was installed in the motor below the exciter to limit the amount of uplift. After many exhaustive tests, a procedure was developed whereby water from the discharge line was introduced into the pump extension

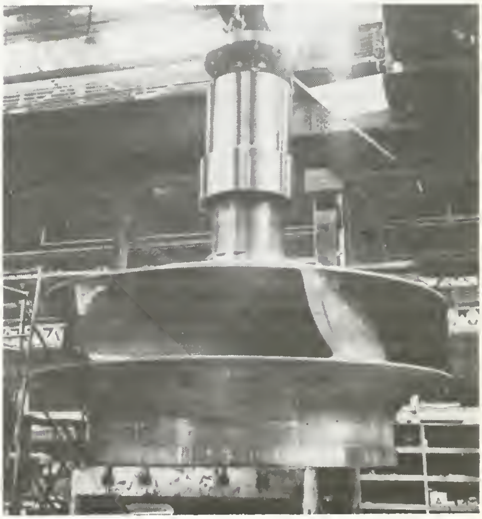

Figure 431. Pump Shaft and Impeller Assembly

piece before venting through the air release and allowing water to enter the pump. This "backfilling" required approximately one and one-half minutes. Concurrently with the backfilling, air from the pump case was vented to the atmosphere from a point below the impeller eye. This process provided a method of filling the pump whereby the impeller was essentially spinning in a bubble of air to minimize the momentum effect of the entering water. After backfilling, the air release valve was opened, allowing water to enter the pump. At this point, the pump primes and the discharge valve opens for pumping. Other problems encountered with these pumps are discussed under the contruction portion of this chapter.

Pump Discharge Valves

A butterfly-type valve was installed on the discharge side of each pump. These valves are used as a shutoff to prevent backflow through the units when they are stopped and to isolate each pump from its discharge line for inspection and maintenance. Each valve and its appurtenances are located in a separate valve vault at the end of the discharge extension of each pump casing (Figure 432).

Units Nos. 1, 2, and 3 at Buena Vista and Wheeler Ridge have 66-inch-diameter valves, each weighing approximately 20,500 pounds. Units Nos. 4 through 10 at Buena Vista and Units Nos. 4 through 9 at Wheeler Ridge have 90-inch-diameter valves, each weighing approximately 31,000 pounds.

The three basic components of each butterfly valve are the body, the disc, and the hydraulic cylinder for opening and closing the valve (Figures 433 and 434). The disc has a nonadjustable, replaceable, bronze seat on its periphery, while the valve body has a mating monel seat which is replaceable as well as adjustable by means of exterior bolts.

The disc is mounted on a horizontal shaft which rotates 88 degrees to open or close the valve (Figure 435). When fully closed, the disc seats at an angle of 88 degrees (two degrees from vertical). When fully open, the disc is parallel to water flow. Also, the disc is fastened to the shaft by fitted taper pins. One end of the shaft is connected to the valve disc operating mechanism, which is composed of an operating cylinder, piston, piston rod, cross-head, connecting linkage, locking device, and operating lever.

The cylinder is double-acting, with the control system set up to simultaneously vent one side of the cylinder to the oil sump tank and allow oil to enter the other side under high pressure from the accumulator tank. Rate of valve movement is controlled by a metering valve on the discharge side of the cylinder.

Each valve disc is rotated by its individual hydraulic system, pressurized by an air-over-oil accumulator. Each system, operating at a pressure of 500 pounds per square inch (psi), is capable of one opening cycle and two closing cycles, after which system pressure is reduced to 375 psi.

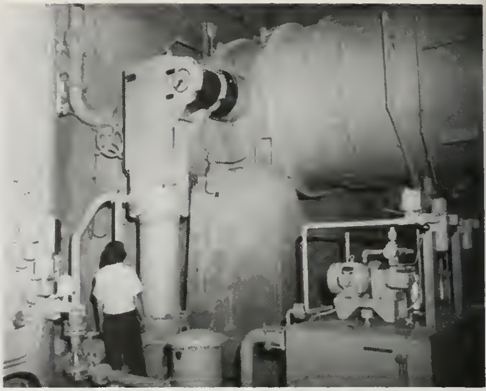
Figure 432. Butterfly Valve Gallery

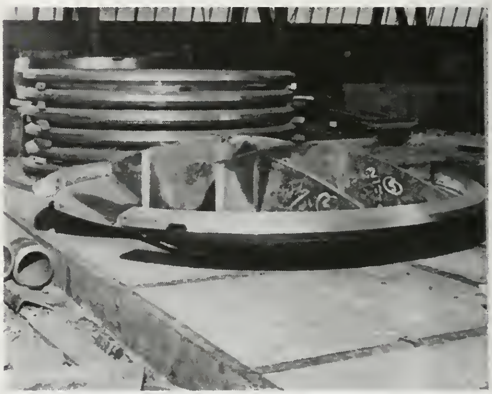
Figure 433. Fabrication of Butterfly Discs

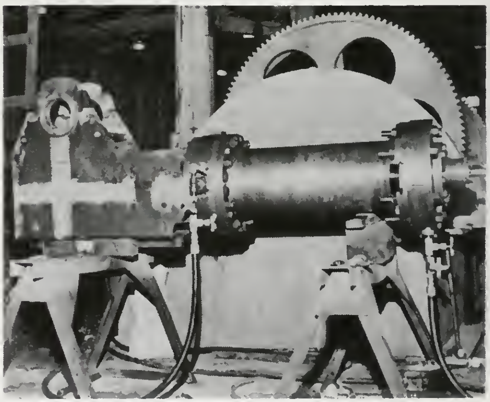
Figure 434. Testing of Valve Operating Cylinder

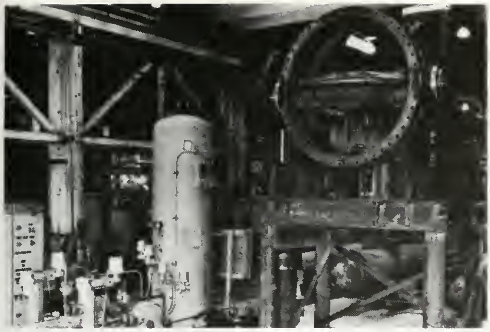

Figure 435. Butterfly Valve on Test Stand

Equipment in each system includes an oil accumulator; oil sump tank and pumps; air compressor; directional and flow control valves; hydraulic control panel; valve control center; and necessary piping, wiring, and instruments. The air compressor and two hydraulic oil pumps supply air and hydraulic fluid, respectively, to the accumulator. The compressor and pumps normally are operated automatically but can be operated manually from the valve control center.

Each pump discharge valve normally is operated only in the fully open or closed position and will open or close at an approximately uniform rate with the closing times being the same for normal or emergency conditions. The valves are set to close in approximately 32 seconds.

Equipment Handling—Cranes

Major pumping plant equipment, including pumps, motors, and discharge valves, is serviced by a 60-ton, indoor, bridge crane.

Each plant also has an outdoor, 10-ton, gantry crane with a trashrack rake. This crane raises, lowers, and transports the intake bulkhead gates and clears the trashracks of debris.

The bridge crane is an electric, cab-operated, overhead, traveling type, with a main 60-ton-capacity hook and an auxiliary 10-ton-capacity hook. A sister-type hook, bored for a lifting pin, is provided for the main hoist.

The rated capacities and speeds of the bridge crane are:

Rated capacity, tons	60
Number of trolleys	1
Rated capacity of main hoist, tons	60
Rated capacity of auxiliary hoist, tons	10
Maximum lift, main hoist, feet—inches	71′—6″
Maximum lift, auxiliary hoist, feet—inches	59′—6″
Span, feet—inches	53′—7⅜″
Hook, Speeds—fpm	
Main (5 step)	0–4
Aux. (5 step)	0–20
Bridge speed—feet per minute (fpm)	97
Trolley speed—fpm	46 full load 50 no load

Brakes are provided for hook, trolley, and crane travel. They include both the electric and hydraulic shoe type, with shunt coil and manual release lever.

The bridge crane is controlled from an operator's cage mounted below one corner of the crane. Access to the crane is at two locations from the plant catwalks. One is from the operator's cab to the sidewall catwalk; the other is by ladder from the operator's cab to the bridge walkway and then from the bridge walkway to a catwalk mounted on the end wall of the Pumping Plant.

The 10-ton gantry crane is an outdoor traveling type, with a trashrack rake. It operates on steel rails in the plant gate deck. The lifting mechanism consists of a lifting beam suspended from twin snatch blocks.

The rated capacity and speeds of the gantry crane are as follows:

Rated capacity, tons	10
Number of trolleys	1
Span, feet	14
Hoist speed with maximum working load, fpm (two speeds)	8 to 12 2 to 3
Gantry travel speed with maximum working load, fpm	30 to 40
Trolley travel speed with maximum working load, fpm	3 to 5
Maximum lift, feet	30
Trashrack rake maximum lift, feet	47
Trashrack rake speed, fpm	32
Trashrack rake capacity, pounds	2,000

Hydraulic Transients

Surge protection as well as reverse speed control are provided by one speed discharge valve closure.

The calculated upsurge, downsurge, and reverse-speed conditions with a single speed closure of 32 seconds were well within the design limits. Field tests verified the calculations.

Auxiliary Service Systems

The auxiliary service systems at these plants are detailed in Chapter I of this volume. Items unique to these plants are noted below.

Raw Water Systems. Raw water is drawn downstream of the discharge valves on Units Nos. 3 through 10. It is then piped to the mechanical gallery where its pressure is reduced to 50 psi by four pressure-reducing stations. Water from this system is used for cooling water to the motors and pumps, flushing water to the pump wear rings, condensing water to the air-conditioning system, pressure supply to the dewatering sump eductor and, at Wheeler Ridge, as a supply to the water treatment plant. At Buena Vista, the water treatment plant supply is taken from the plant forebay. Provisions were made at Wheeler Ridge to supply the water treatment plant from the forebay, if necessary.

Two cooling water pumps located in the access gallery are capable of supplying raw water in the event pressure in the raw water supply header drops below a set value (Figure 436). These pumps also are used to fill a discharge line in the event all discharge lines are dewatered.

Automatic, self-cleaning, rotating-type strainers were installed at each pressure-reducing station and at each cooling water pump (Figure 437). They are automatically backwashed when the pressure drop across their straining elements exceeds 5 psi or by a set time interval that overrides the pressure switch.

Oil Systems. Two different oils are used in the plants: one for lubricating the pump and motor bearings, and one for the hydraulic fluid in the pump discharge valve hydraulic system. The oils are a high-grade turbine type with the pump and motor systems having a viscosity at 100 degrees Fahrenheit of 280 to 330 SSU. The discharge valve systems oil has a viscosity at 100 degrees Fahrenheit of 140 to 160 SSU.

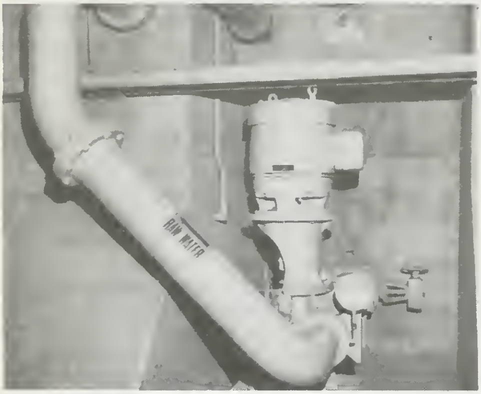

Figure 436. Raw Water Pump

Figure 437. Cooling Water Pump Gallery

Electrical Features

General

The electrical installations at the two plants are nearly identical. Buena Vista has one more pumping unit than Wheeler Ridge. The installation includes a 230-kV switchyard; power transformers; motors; switchgear; and auxiliary systems for station service, communication, and protection of equipment and personnel (Figure 438).

Chapter I of this volume contains information on the electrical equipment and systems for Buena Vista and Wheeler Ridge which are common to other plants in the State Water Project. Information and descriptions which are unique to these plants are included in the following sections.

Description of Equipment and Systems

The ten motors at Buena Vista and nine motors at Wheeler Ridge are started full-voltage with water depressed from the pump case. The motors are wye-connected with the neutral connected to ground through the high-voltage winding of a distribution transformer, and the low-voltage winding is connected to a resistor and relays. This transformer-resistor combination reduces unbalanced and ground fault currents to a harmless value. The relays trip the motor off the line for abnormal unbalances or ground faults. Capacitors and lightning arresters on the line side of each motor protect windings from voltage surges.

Two 230-kV transmission lines serve each switchyard. Two circuit breakers and associated disconnect switches protect the two power transformers and transmission lines and also serve for switching purposes.

The power transformers are located near the Pumping Plants and reduce voltage from 220 kV to 13.2 kV. Lightning arresters are mounted on the transformers (Figure 439).

The metal-clad switchgear lineup includes circuit breakers for operation and protection of the motors and station service transformers. Nonsegregated-phase bus connects the switchgear to the power transformers. The larger motors are also connected to their circuit breakers with this same type of bus. Cables are used for connections of the smaller motors.

A double-ended substation is used for the station service equipment which includes two transformers, main, tie, and distribution breakers (Figure 440). The transformers reduce voltage from 13.2 kV to the distribution voltage of 480 volts (Figure 441).

Duplex walk-in-type switchboards, one for each unit, are utilized to mount and connect the protective relays, instruments, meters, annunciators, and the operating panel (Figures 442 and 443).

A control room is provided in each plant for normal operation. Each unit also may be controlled in the local mode from its unit switchboard. A computer in the control room provides the necessary control, monitoring, annunciation, display, and data logging. The plant also may be operated from a remote control center, which is described in Volume V of this bulletin.

Equipment Ratings

Motors

Manufacturer: Westinghouse Electric Corporation
Type: Vertical-shaft, synchronous
Power factor: 95%
Volts: 13,200

Motors Nos. 1, 2, and 3—Buena Vista
Horsepower: 8,500
Speed: 360 rpm

Motors Nos. 4 through 10—Buena Vista
Horsepower: 17,000
Speed: 257 rpm

Motors Nos. 1, 2, and 3—Wheeler Ridge
Horsepower: 10,000
Speed: 400 rpm

Motors Nos. 4 through 9—Wheeler Ridge
Horsepower: 20,000
Speed: 277 rpm

Power Transformers

Manufacturer: General Electric Company
Volts: 220-13.2 kV, grounded-wye
Taps: In the high-voltage winding, 2½ and 5% above and below rated voltage
Phase: 3
Type: OA/FA
Connection: Wye-Delta

Transformer No. 1—Buena Vista
kVA: 45,750/61,000

Transformer No. 2—Buena Vista
kVA: 40,875/54,500

Transformer No. 1—Wheeler Ridge
kVA: 43,875/58,500

Transformer No. 2—Wheeler Ridge
kVA: 49,125/65,500

Station Service

Number of transformers: 2
Volts: 13,200—480Y/277
Phase: 3
Type: AA/FA
kVA: 1,000/1,333
Emergency engine-generator: 75 kW, 480 volts, 3 phase

Motor Starting Method

As previously mentioned, the motors are started with full voltage and with the pump casing dewatered. Since they are started daily for off-peak pumping, the capability to operate under these starting conditions without excessive maintenance or rewinding was a major concern.

Figure 438. Motors and Unit Control Boards—Buena Vista

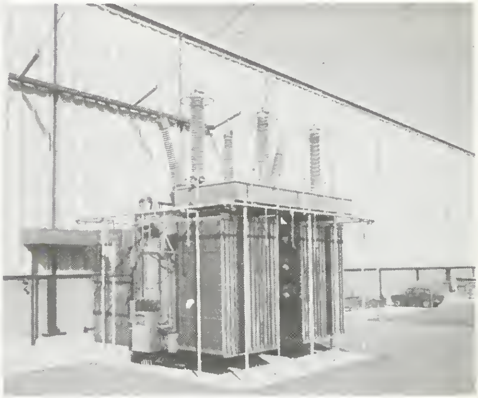

Figure 439. 45.75/61.0-MVA Transformers—Bueno Vista

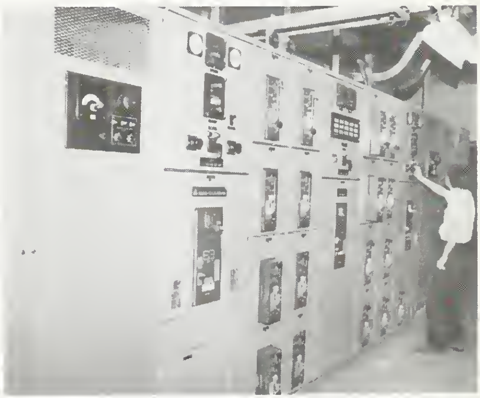

Figure 440. 480-Volt Station Service Substation—Wheeler Ridge

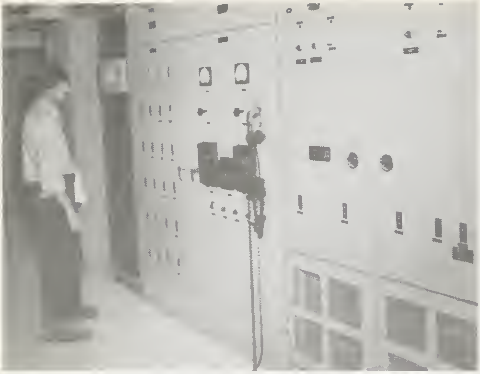

Figure 441. 125-Volt Direct-Current Distribution Board—Buena Vist

Figure 442. Unit No. 5 Control Board—Buena Vista

The choice between full-voltage starting and reduced-voltage starting was made after consideration of the following: motor load and speed, effect of inrush and voltage drop on the utility system, and economics. The horsepower per pole was used as a guide to compare these plants with plants constructed by others and to evaluate their experience records. The values for these motors were sufficiently low to warrant the selection of full-voltage starting. The calculated values of inrush current for the motor sizes indicated that the utility system would not be adversely affected by the voltage drop. The utility system, with several interconnections in the area of the plants, is a strong system. The study also recognized the economic aspects of the starting alternatives. Full-voltage starting required a minimum of equipment; consequently, costs would be less and starting reliability greater. Water was depressed from the pump impeller to reduce the starting torque requirements and motor costs (Figures 444 and 445).

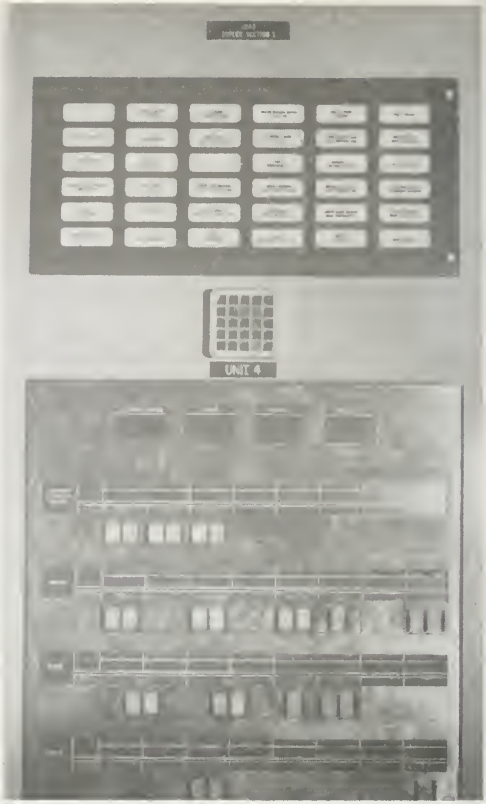

Figure 443. Unit No. 4 Display Panel—Buena Vista

Figure 444. 20,000-Horsepower Motor Exciter—Wheeler Ridge

230-kV Interconnections

Two transmission lines supply power to Buena Vista, Wheeler Ridge, and Wind Gap Pumping Plants. A load external to department plants also is supplied over these lines by the utility company. The switchyard contains two transmission lines connected to two power transformers through circuit breakers. A bypass switch was installed to connect the two circuits together between the transformers and circuit breakers. Normally, the bypass switch is open and each line supplies one transformer or half of the plant. This arrangement allows one-half of the yard to be shut down for maintenance by closing the bypass switch and opening a circuit breaker. The entire pumping plant is then supplied from the remaining transmission line circuit (Figure 446).

In the initial design of the switchyard, both ring bus and main-and-transfer bus arrangements also were considered. These two layouts are more advantageous where greater switching flexibility or future growth must be considered, such as at generating plants. The two alternate layouts also require more equipment and more steel structures than the selected switchyard.

The switchyard finally selected provides sufficient flexibility for the load and transmission lines utilized. Full protection is provided for expected situations. Since costs were much in favor of the two-breaker yard and since no future expansion was anticipated, this simpler arrangement was selected.

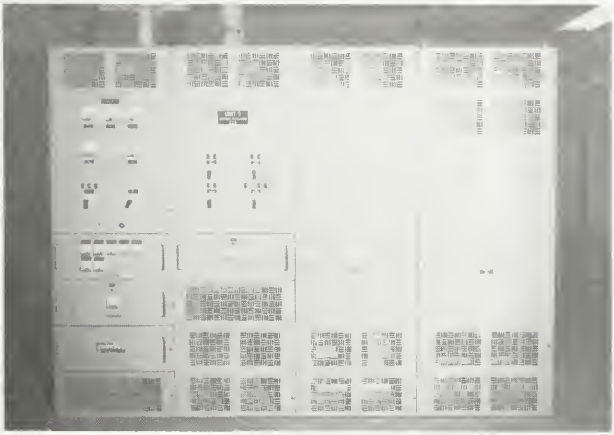

Figure 445. Field Excitation and Voltage Regulation Equipment—Wheeler Ridge

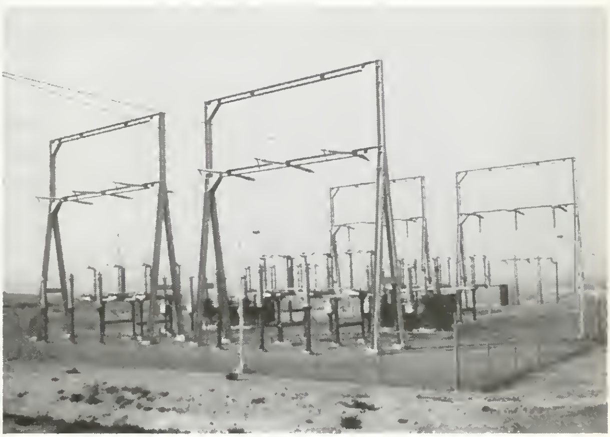

Figure 446. 230-kV Switchyard—Buena Vista

Construction—Buena Vista Pumping Plant

Contract Administration

Four principal construction contracts and numerous furnish and install contracts were awarded for Buena Vista Pumping Plant. The intake channel and bowl were excavated under Specification No. 65-36. The plant and lower portion of the discharge line (1,079,233 pounds) were constructed under Specification No. 67-47, and the major portion of the discharge lines (3,176,162 pounds) was constructed under Specification No. 67-69. Some of the contracts included equipment for other plants. General information about the major contracts is shown in Table 9.

Bowl and Intake Channel Excavation

Initial excavation started in November 1965. Bowl excavation was completed November 1966 and the intake in January 1967.

The major portion of the excavated material was placed in waste areas. Minor amounts were placed in the spill basin dike, in low areas, and in the left side of the canal prism at the upstream end of the intake channel.

Earthwork was primarily performed with scraper-tractor combination units.The relatively flat terrain was ideally suited for large-scale earth-moving operations. The excavation and waste areas were arranged so that the loaded scrapers usually traveled downhill to the waste areas. A total of 9,703,000 cubic yards was removed from the bowl and intake channel (Figure 447).

Layers of expansive clays were overexcavated 4½ feet normal to the intake channel side slopes in various locations and replaced with a total of 62,100 cubic yards of clayey sand.

Surface Water Removal

A complete drainage system was installed to control runoff in the area excavated for the intake channel and pumping plant bowl. The system consists of a network of drop inlets, asbestos cement pipes, drainage ditches, and outlet facilities.

Ground Water Removal

A ground water pumping system was installed to lower artesian pressures prior to final structural excavation in the pumping plant bowl. The system included four wells with pumps, five observation wells, and a discharge line from the pumps to an evaporation pond. The total pumping capacity was 200 gallons per minute.

TABLE 9. **Major Contracts—Buena Vista Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Intake channel	65-36	$3,447,228	$3,601,155	$18,041	9/28/65	10/ 6/67	Griffith Co.
Pumps	67-08	2,229,350	2,545,164	—2,359	4/12/67	5/19/72	Allis-Chalmers Mfg. Co.
Pump discharge valves (including Wheeler Ridge Pumping Plant)	67-41	2,047,609	2,330,098	9,465	9/13/67	1/26/71	Yuba Industries, Inc.
Power transformers (including Wheeler Ridge Pumping Plant)	P.O. 07119	726,406	865,963	432	8/ 7/67	3/28/72	General Electric Co.
Plant construction	67-47	6,865,663	7,106,521	126,433	11/ 8/67	6/10/69	Guy F. Atkinson Co.
Bridge cranes (including Wheeler Ridge, Wind Gap, and Oso Pumping Plants)	67-57	423,850	453,676	10,622	12/13/67	10/13/69	Crane Hoist Engineering & Mfg. Co.
Motors	67-63	3,156,957	3,744,530	31,056	2/16/68	12/14/72	Westinghouse Electric Corp.
Aqueduct,* Buena Vista Pumping Plant to Wheeler Ridge Pumping Plant	67-69	19,975,006	20,398,353	144,076	1/22/68	8/31/70	Griffith Co.
Power circuit breakers (including Wheeler Ridge and Wind Gap Pumping Plants)	67-70	409,840	437,204	2,701	12/29/67	6/24/71	Westinghouse Electric Corp.
Switchgear (including Wheeler Ridge Pumping Plant)	68-05	1,062,100	1,224,887	99,003	5/ 2/68	5/ 4/71	Golden Gate Switchboard Co.
Station Service Distribution Centers (including Wheeler Ridge Pumping Plant)	68-10	194,256	212,506	7,496	3/ 7/68	6/23/71	Allis-Chalmers Mfg. Co.
Completion contract	68-45	2,657,682	3,600,519	686,518	1/25/69	7/ 1/72	Dravo Corp.

* Includes steel discharge lines and appurtenances for Buena Vista Pumping Plant

Structural Excavation and Backfill

Structural excavation under the pumping plant contract, Specification No. 67-47, involved excavation for a portion of the pumping plant discharge lines, hauling of excess and unsuitable excavated material to spoil areas, and final excavation of the pumping plant bowl. Final excavation and concrete placements for the plant substructure were performed in three stages. The weight of the concrete reloaded the foundation and limited rebound which could have adversely affected the structural stability of the Pumping Plant (Figure 448).

The first-stage excavation was begun during December 1967 and finished under third-stage excavation performed during August 1968. Total structure excavation was 78,804 cubic yards.

Structural backfill against concrete structures was placed between February 1968 and May 1969. Approximately 59,000 cubic yards of structural backfill material was placed. The required 95% relative compaction was obtained using a vibratory compactor in accessible areas and a one-man whacker near walls and other confined areas.

Pneumatically Applied Mortar

The excavated surfaces of the pumping plant foundation were protected with a 2-inch coating of pneumatically applied motor. The mortar was applied the same day as the foundation was exposed to prevent slaking and was covered by concrete within 90 days.

In one of the bays, the "gunite" mortar surface heaved as a result of ground movements. Rather than replacing the mortar, it was removed just prior to placement of the concrete foundation.

Concrete Placement

In the monolithic reinforced-concrete structure located below the finished grade of the motor floor, a total of approximately 48,000 cubic yards of concrete was placed along with 5,924,507 pounds of reinforcing bars. An additional 4,500 cubic yards were placed to complete the structure when the mechanical and electrical equipment was installed under the completion contract, Specification No. 68-45.

A 50-ton batch plant was located about ¼ of a mile from the pumping plant site. End-dump trucks were modified to carry two 4-cubic-yard concrete buckets equipped with air-operated discharge gates. A crawler crane with a 200-foot boom was used to place the concrete in the forms.

Discharge Lines

The discharge lines were installed under two different contracts. The lower portions, including tapers, manifolds, and encased portions, were installed under Specification No. 67-47 as part of the pumping plant contract (Figure 449). The major portion of the lines, outlet works, and siphon breaker structure were in-

Figure 447. Aerial View of Pumping Plant Bowl Just Prior to Pumping Plant Contract

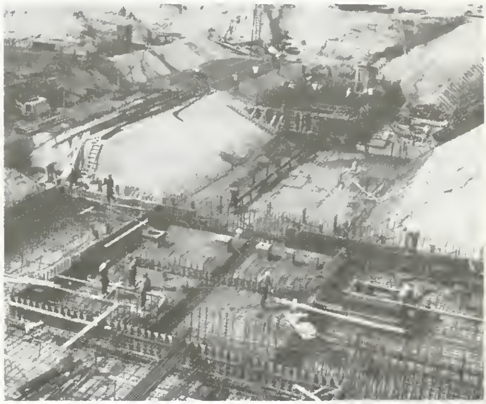

Figure 448. View From East End of Excavation—Buena Vista

Figure 449. Aerial View of Discharge Manifold and Discharge Lines Nos. 1 Through 5 in Place—Buena Vista

stalled under Specification No. 67-69 as part of the downstream canal reach contract (Figure 450).

Installation of the taper sections was the first work completed on the discharge lines. The contractor had rushed delivery of the taper sections to avoid setting them into the designed concrete blockouts and the attendent placement of concrete in confined areas.

The taper sections were coated with a 1-foot strip of coal-tar epoxy at edges of concrete embedments, thereby eliminating possible discoloration on the concrete walls and further protecting the tapers from corrosion.

The discharge lines and appurtenances were sandblasted. The interior was coated with coal-tar epoxy and the exterior was coated with inorganic zinc silicate. The concrete encasements proceeded routinely, along with the pumping plant substructure placements, using the same batch plant and placing crew.

Although many of the pipe sections weighed only approximately 10 tons, a 90-ton-capacity crane was used because of the reach involved.

After the Department accepted the radiographed welds, the contractor hydrotested the manifold section. The test involved: (1) bringing the pressures up to 150 psi and holding for one hour, (2) releasing the pressure, and (3) repressurizing to 150 psi and holding for a second hour.

Hydrotesting of the eight discharge lines was performed similarly following concrete encasement and installation of the sleeve-coupling roll-out sections.

Other Construction

Other construction included the pumping plant superstructure, pumps, motors, bridge crane, transformers and switchyard, and control system. The plant was completed July 1, 1972.

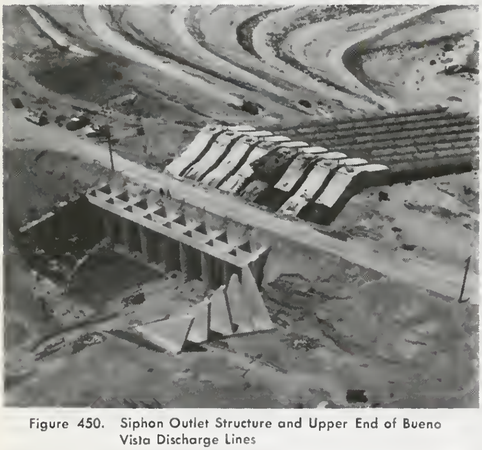

Figure 450. Siphon Outlet Structure and Upper End of Bueno Vista Discharge Lines

Construction—Wheeler Ridge Pumping Plant

Contract Administration

Numerous construction contracts were issued to build this plant. Several of these contracts included equipment for other plants. General information about the major contracts for construction of this plant is shown in Table 10.

Preconsolidation

Preconsolidation of subsurface soils was performed in areas where facilities were constructed in cuts less than 100 feet deep. Work performed under preconsolidation contracts is described in detail in Volume II of this bulletin.

Bowl and Intake Channel Excavation

Excavation for the bowl and intake channel began in September 1966 and was completed in May 1967. A total of 7,252,000 cubic yards of material was excavated and wasted in adjacent spoil areas. Twin-engine 40-cubic-yard scrapers loaded by large push dozers were used for excavating and hauling the material. Excavation slopes were finished by large dozers with slope boards attached to the dozer blade. Some difficulty was encountered in excavating the western end of the intake channel due to the residual moisture from the preconsolidation ponds in the area.

Dewatering Operations

The drainage system for the bowl and intake channel for the plant consisted of: training dikes, drainage channels, air-blown-mortar-lined ditches, corrugated-metal pipe culverts, and asbestos cement pipe slope drains. The training dikes and drainage channels were constructed in conjunction with the earthwork operations and the culverts in conjunction with access roads. Surface runoff and cure water were collected in the main sump of the plant's service bay and pumped out of the bowl. Ground water was not encountered during excavation so no dewatering was necessary prior to construction of the sump.

Structural Excavation and Backfill

Excavation for the plant foundation was performed during January and February 1968, except for a 3-inch layer left in place until just before the foundation was coated with pneumatically placed mortar. Up to six tractors towing 8-cubic-yard self-loading scrapers were used to do the excavation. Slopes were cut and trimmed with graders and a dozer. Excavated material was stockpiled in the canal intake channel and adjacent to the west end of the plant foundation for later use as structural backfill (Figure 451). Excavation of the pier foundations for the discharge lines was a trenching operation using self-loading scrapers that excavated across the discharge alignment for a row of seven pier footings.

TABLE 10. **Major Contracts—Wheeler Ridge Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Intake channels, Wheeler Ridge and Wind Gap Pumping Plants	66-11	$4,575,273	$4,842,573	$10,505	4/ 5/66	8/31/67	Gordon H. Ball Enterprises & Altfillisch-Fulton Co.
Pumps	67-19	2,297,000	2,680,000 (Est.)	—134*	6/ 5/67	12/74 (Est.)	Allis-Chalmers Mfg. Co.
Pump discharge valves (including Buena Vista Pumping Plant)	67-41	2,047,609	2,330,098	9,465	9/13/67	1/26/71	Yuba Industries, Inc.
Power transformers (including Buena Vista Pumping Plant)	P.O. 07119	726,406	865,963	432	8/ 7/67	3/28/72	General Electric Co.
Pumping plant and discharge Lines	67-52	8,813,241	9,077,702	122,296	11/17/67	10/31/69	Al Johnson Construction Co.
Bridge cranes (including Buena Vista, Wind Gap, and Oso Pumping Plants)	67-57	423,850	453,676	10,622	12/13/67	10/13/69	Crane Hoist Engineering & Mfg. Co.
Motors	67-64	2,979,726	3,546,168	36,252	2/26/68	8/26/72	Westinghouse Electric Corp.
Power circuit breakers (including Buena Vista and Wind Gap Pumping Plants)	67-70	409,840	437,204	2,701	12/29/67	6/24/71	Westinghouse Electric Corp.
Switchgear (including Buena Vista Pumping Plant)	68-05	1,062,100	1,224,887	99,003	5/ 2/68	5/ 4/71	Golden Gate Switchboard Co.
Station service and distribution centers (including Buena Vista Pumping Plant)	68-10	194,256	212,506	7,496	3/ 7/68	6/23/71	Allis-Chalmers Mfg. Co.
Completion contract (including Wind Gap Pumping Plant)	68-49	6,345,852	7,740,917	1,006,173	4/ 1/69	2/ 6/73	Wismer & Becker Contracting Engineers

* As of November 1974

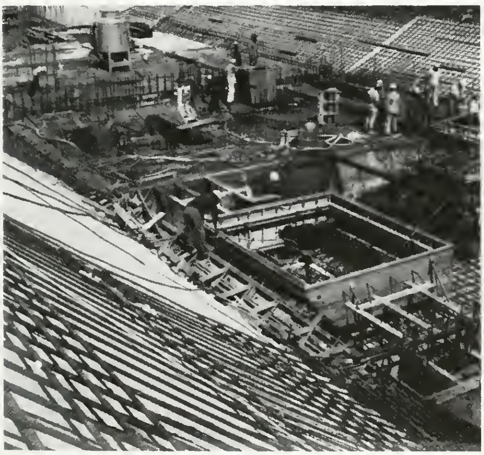

Figure 451. View Across Wheeler Ridge Plant Foundation Area With Service Bay on Left

Excavation for the encased portion of the discharge lines was performed from September to November 1968, with the excavated material used as backfill around the plant.

Pneumatically Applied Mortar

A layer of mortar (shotcrete) was applied on all load bearing surfaces of the foundation excavation. It was applied immediately after completing the excavation to protect the surfaces until they were covered by structural and backfill concrete (Figure 452).

Concrete Placement

The portable batch plant had a rated capacity of 65 cubic yards per hour. Aggregates were delivered to the plant by the 20-cubic-yard, end-dump, semitruck and trailers. Aggregates were separated into three sizes—2-inch, 1-inch, and No. 5 sieve—by a horizontal, vibrating, finish screen. Concrete was mixed and discharged from the batch plant into a 10-cubic-yard tilting-drum agitator mounted on a ten-wheel truck, then transported to the placement location and transferred directly into the placing bucket.

Figure 452. Shotcrete Equipment Working on Upstream Slopes of Pumping Plant Excavation—Wheeler Ridge

Concrete operations were directed toward reloading the foundation as soon as practical after excavation was completed. The service bay concrete was placed first up to elevation 477 feet followed by placement for the unit bays. All placements were limited by the specifications to a maximum of 20-foot lifts.

Suction intake forms were constructed of wood and coated with a single-component fast-setting film (Figure 453).

The concrete work in the plant was completed in May 1969. Miscellaneous items, including transformer pads, crane stops, rail embedment, and grouting, were completed shortly thereafter.

Discharge Lines

In October 1968, the subcontractor for the discharge lines began to set pipe support trunnions in place on the previously installed concrete piers. A 130-ton-capacity crane was used to set the pipe sections in place. Installation of the pipe sections, as well as the trunnions, proceeded from the top of the slope down to the Pumping Plant. After placing a section of each of the seven discharge lines (109-inch diameter), the crane moved downhill to the next row of pipe sections. As many as 24 pipe sections were set per shift (Figures 454 and 455).

Pipefitters started aligning the pipe sections to line and grade in November 1968. The sections were then welded and radiographed, starting with sections to be embedded in concrete. Truing out-of-round pipe ends was accomplished using a fabricated eight-leg "spider".

Prior to concrete embedment, all tapers were rounded out to a $\frac{1}{4}$-inch tolerance followed by installation of roll-out sections. The roll-out sections sagged from $\frac{1}{2}$ to $\frac{7}{8}$ inches after the lines were filled with water and the cribbing was removed. Disassembly and reinstallation of the couplings at the roll-outs only lessened the sagging. Therefore, six 109-inch-diameter and three 79-inch-diameter coupling spool support systems were furnished and installed under a later contract.

The roll-out section interiors were sandblasted and coated with coal-tar epoxy; all exterior sections were sandblasted and coated with inorganic zinc silicate.

Other Construction

Second-stage concrete and embedment of pump scroll cases in concrete were accomplished under the completion contract, Specification No. 68-49, as well as the installation of much of the piping, wiring, drainage pumps, compressors, water and sewage treatment plants, air conditioning, interior finishing, and yard paving. The work on the completion contract, Specification No. 68-49, was physically completed on February 6, 1973, and the contract was accepted on February 9, 1973.

The computer control system, an important part of this plant, is described in Volume V of this bulletin.

Figure 453. Fabricating Suction Intake Form—Wheeler Ridge

Figure 454. Discharge Line Manifold for Wheeler Ridge During Hydrostatic Testing

Figure 455. View of Partially Constructed Plant—Wheeler Ridge

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 456 through 491).

Figure Number	
456	General Plan—Buena Vista
457	Structural Design Data—Buena Vista
458	Plan at Elevation 304.0—Buena Vista
459	Plan at Elevation 304.0—Buena Vista
460	Plan at Elevation 290.0—Buena Vista
461	Plan at Elevation 290.0—Buena Vista
462	Plan at Elevation 277.5—Buena Vista
463	Plan at Elevation 277.5—Buena Vista
464	Transverse Sections—Buena Vista
465	Longitudinal Section Units Nos. 1 through 5—Buena Vista
466	Longitudinal Section Units Nos. 6 through 10—Buena Vista
467	General Plan—Wheeler Ridge
468	Discharge Lines—Plan and Elevation—Wheeler Ridge
469	Discharge Line Profiles—Wheeler Ridge
470	Discharge Line Manifold—Wheeler Ridge
471	Compressed Air System
472	Water System—Service Bay
473	Water System—Units Nos. 1 through 10
474	Carbon Dioxide Fire-Protection System
475	Lubrication Oil System
476	Dewatering and Pressure Drainage
477	Motor Cooling Water System
478	Pumping Unit Air System
479	Pumping Unit Water System
480	Air, Oil, and Water Piping
481	Piezometer Piping—Details
482	Piezometer Piping—Transverse Sections
483	Siphon Control System—Mechanical
484	Single-Line Diagram—Unit No. 1—Buena Vista
485	Single-Line Diagram—Units Nos. 2 through 9—Buena Vista
486	230-kV Switchyard
487	Bus Duct
488	Switchgear
489	Station Service
490	Cable Trays
491	Direct-Current System

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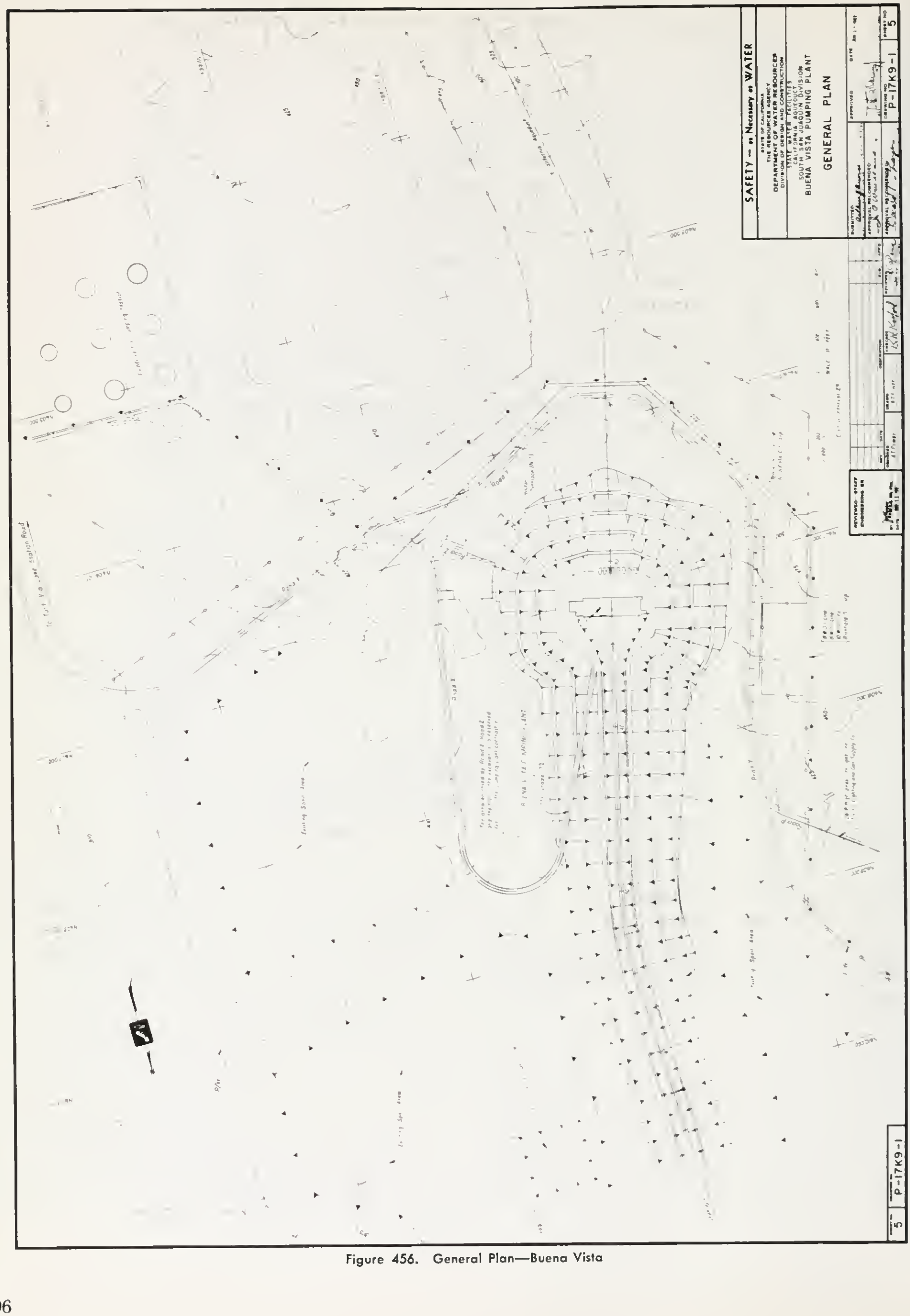

Figure 456. General Plan—Buena Vista

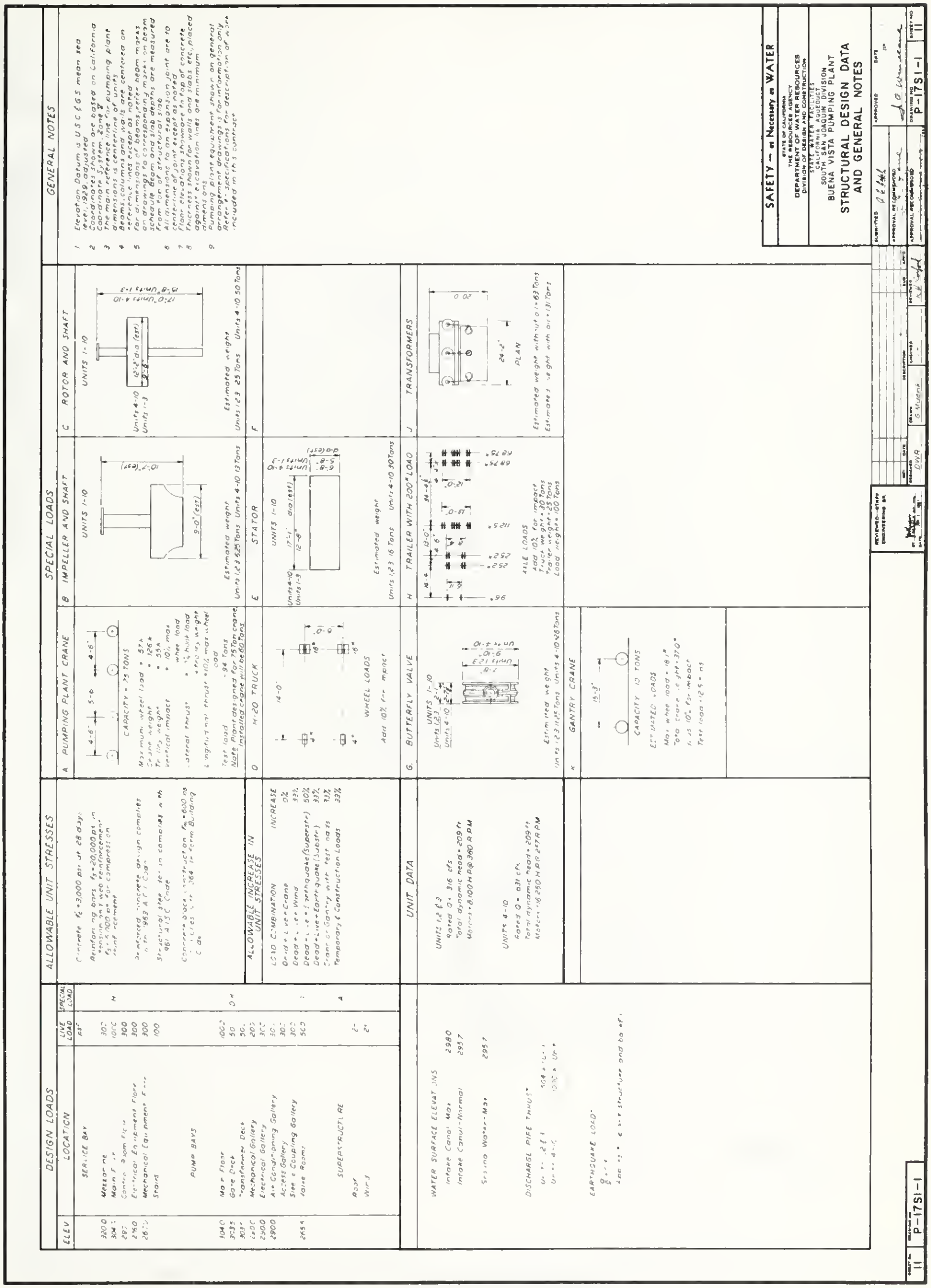

Figure 457. Structural Design Data—Buena Vista

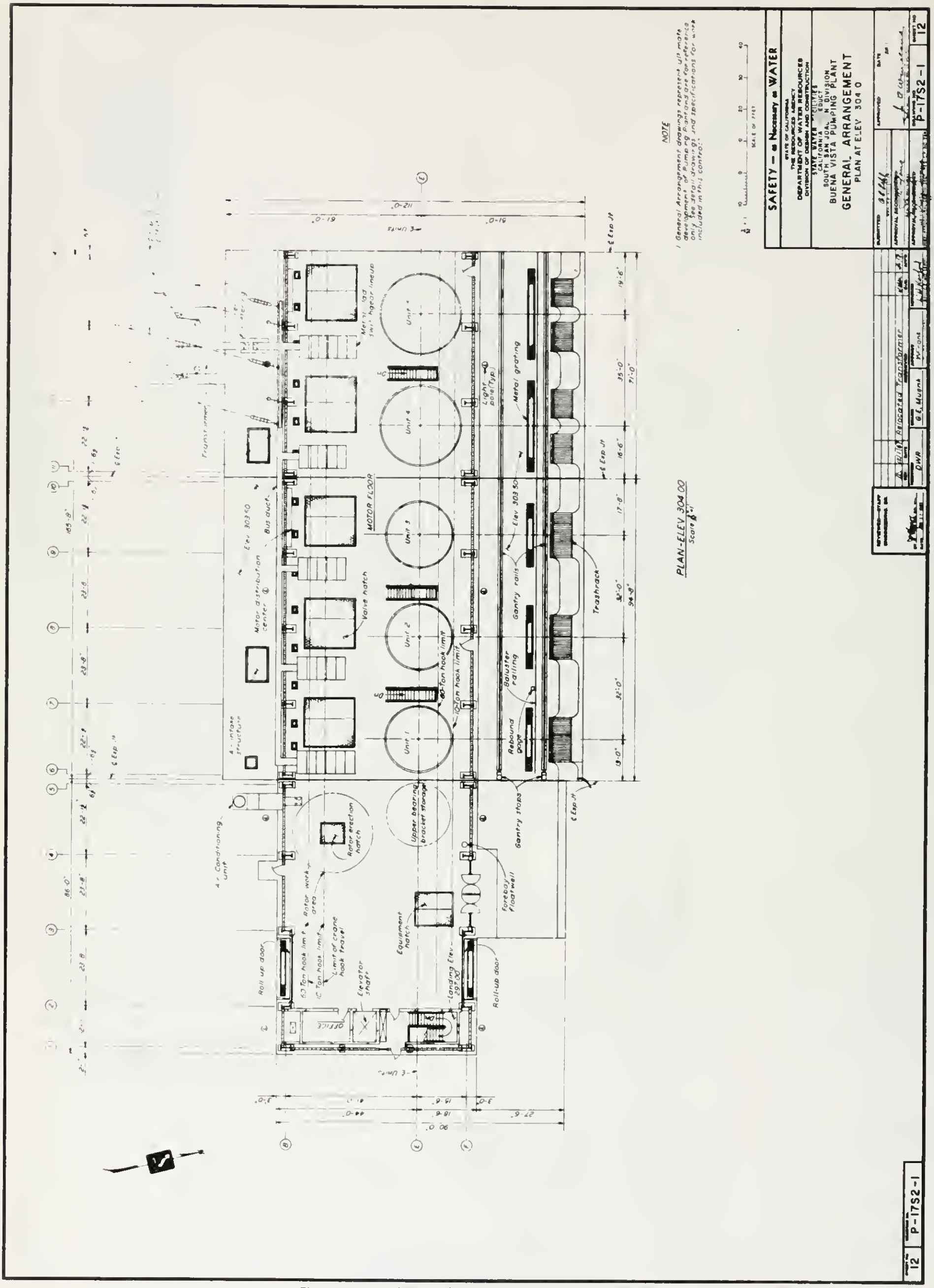

Figure 458. Plan at Elevation 304.0—Buena Vista

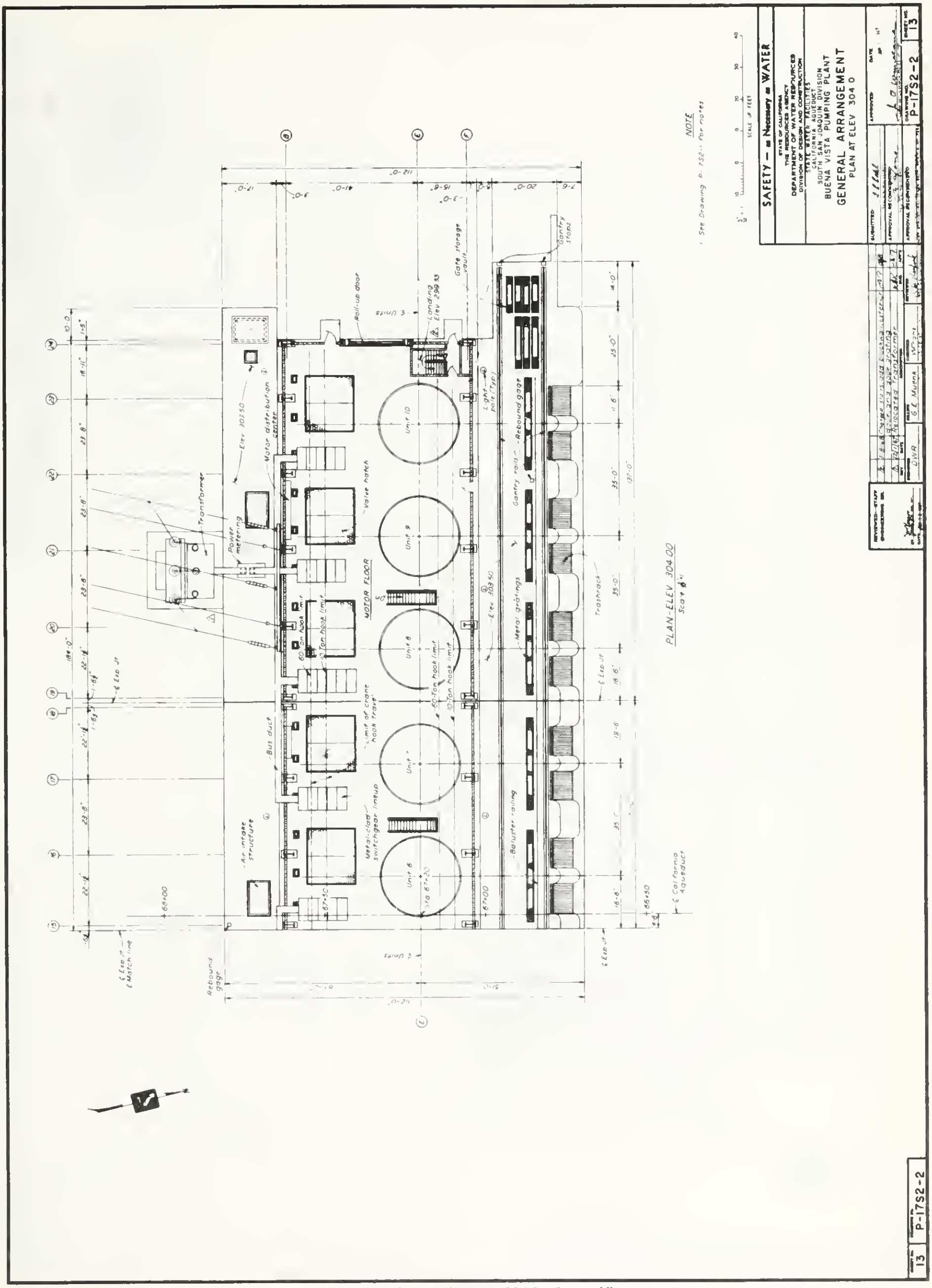

Figure 459. Plan at Elevation 304.0—Buena Vista

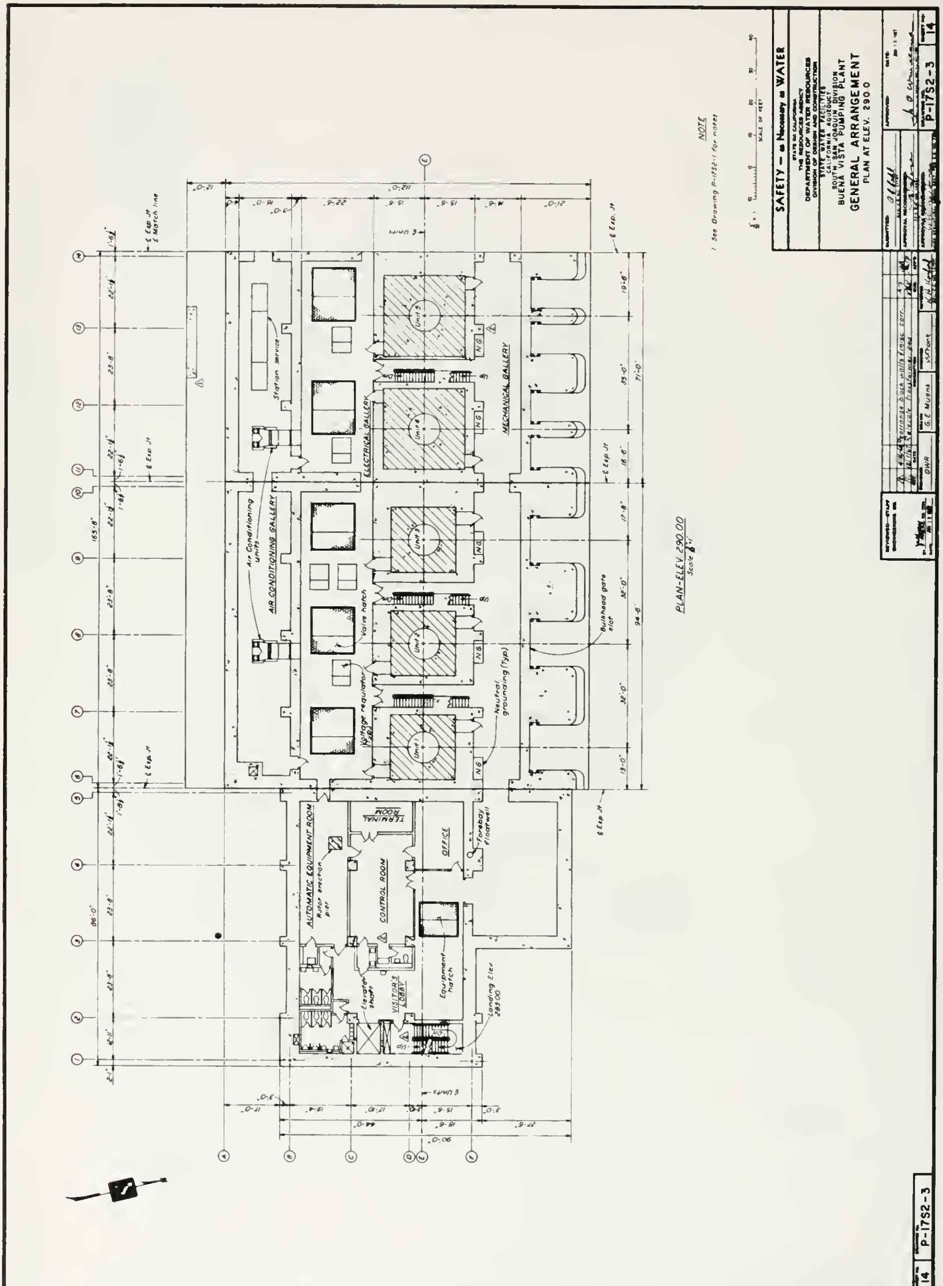

Figure 460. Plan at Elevation 290.0—Buena Vista

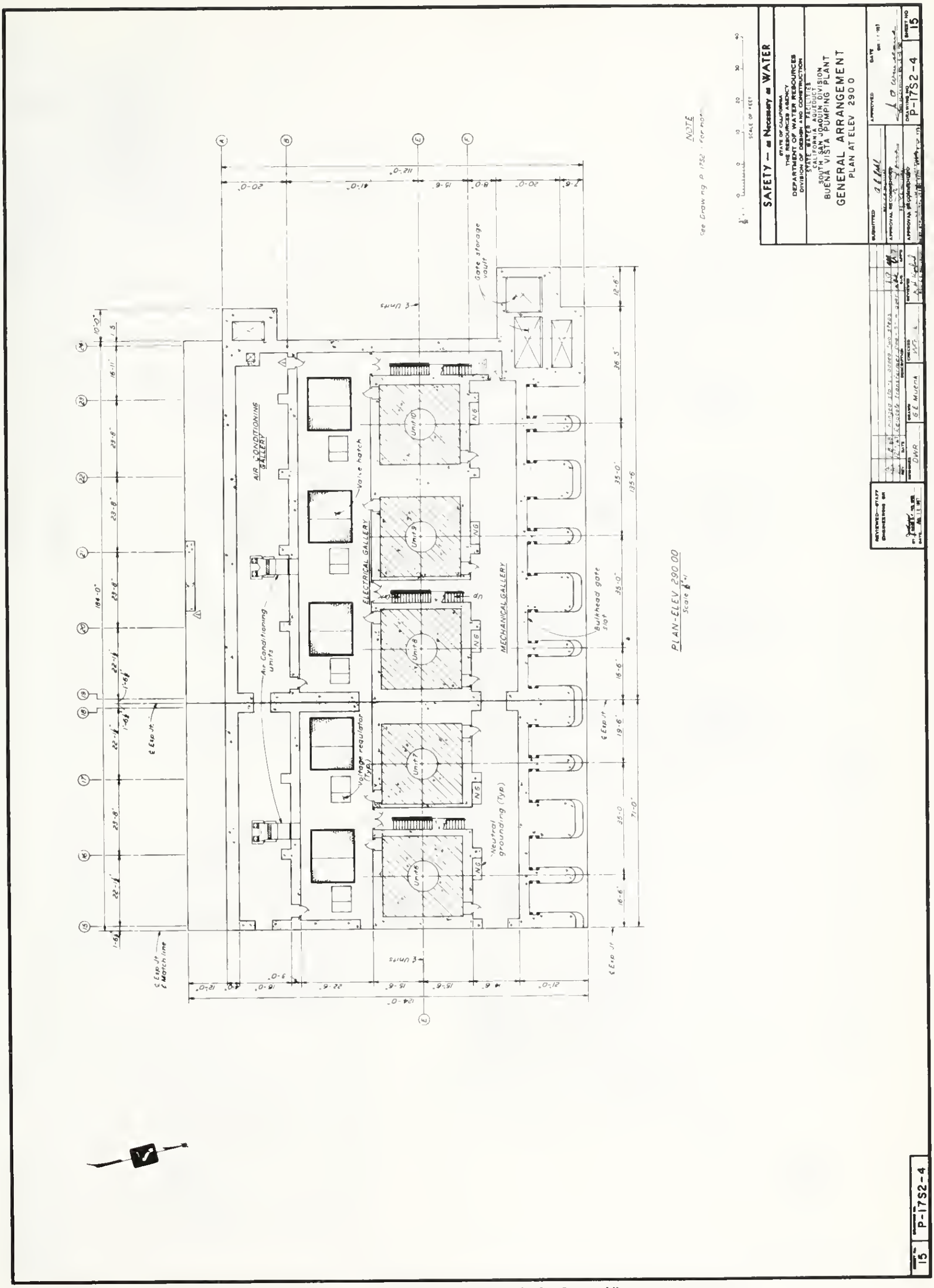

Figure 461. Plan at Elevation 290.0—Buena Vista

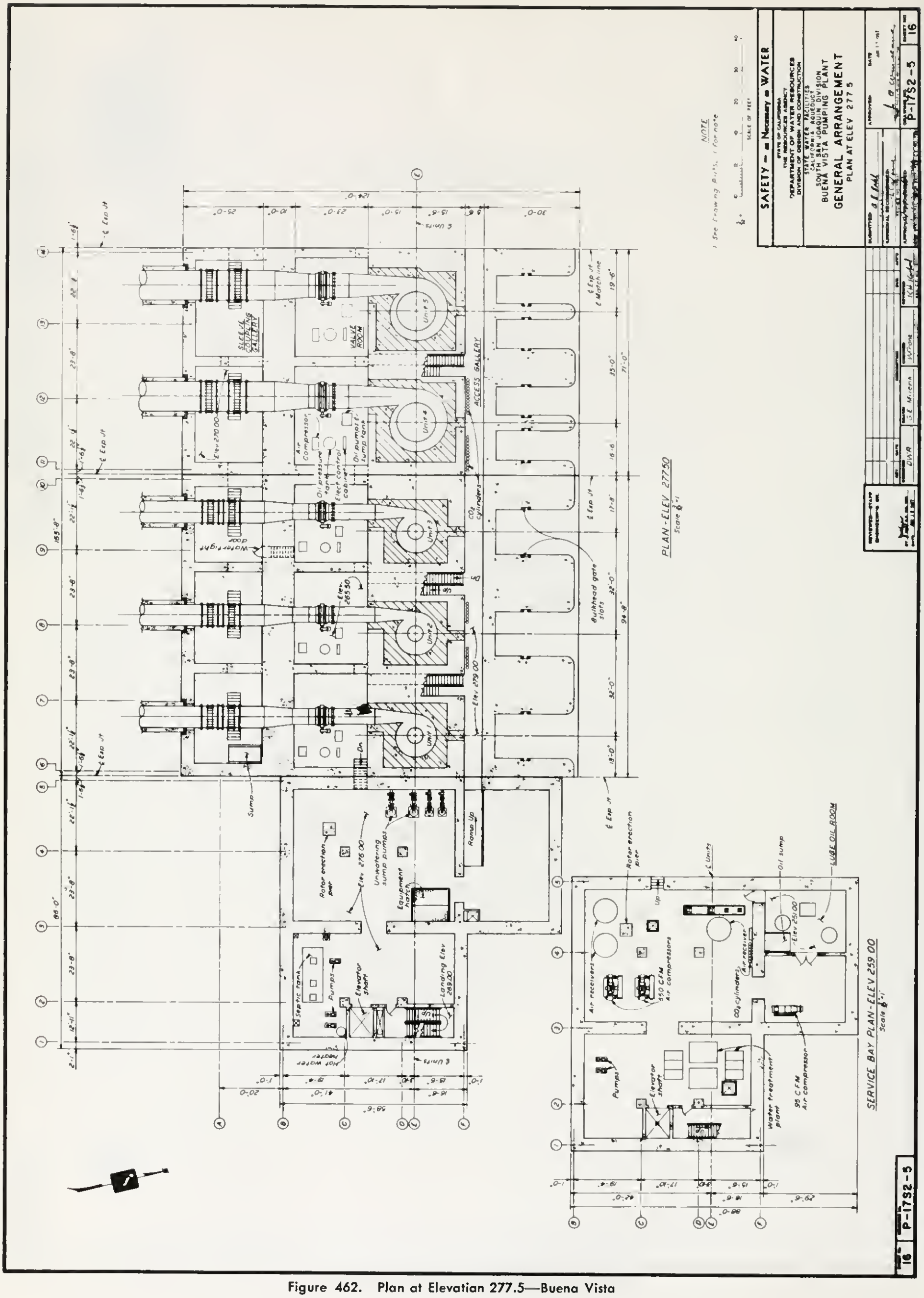

Figure 462. Plan at Elevatian 277.5—Buena Vista

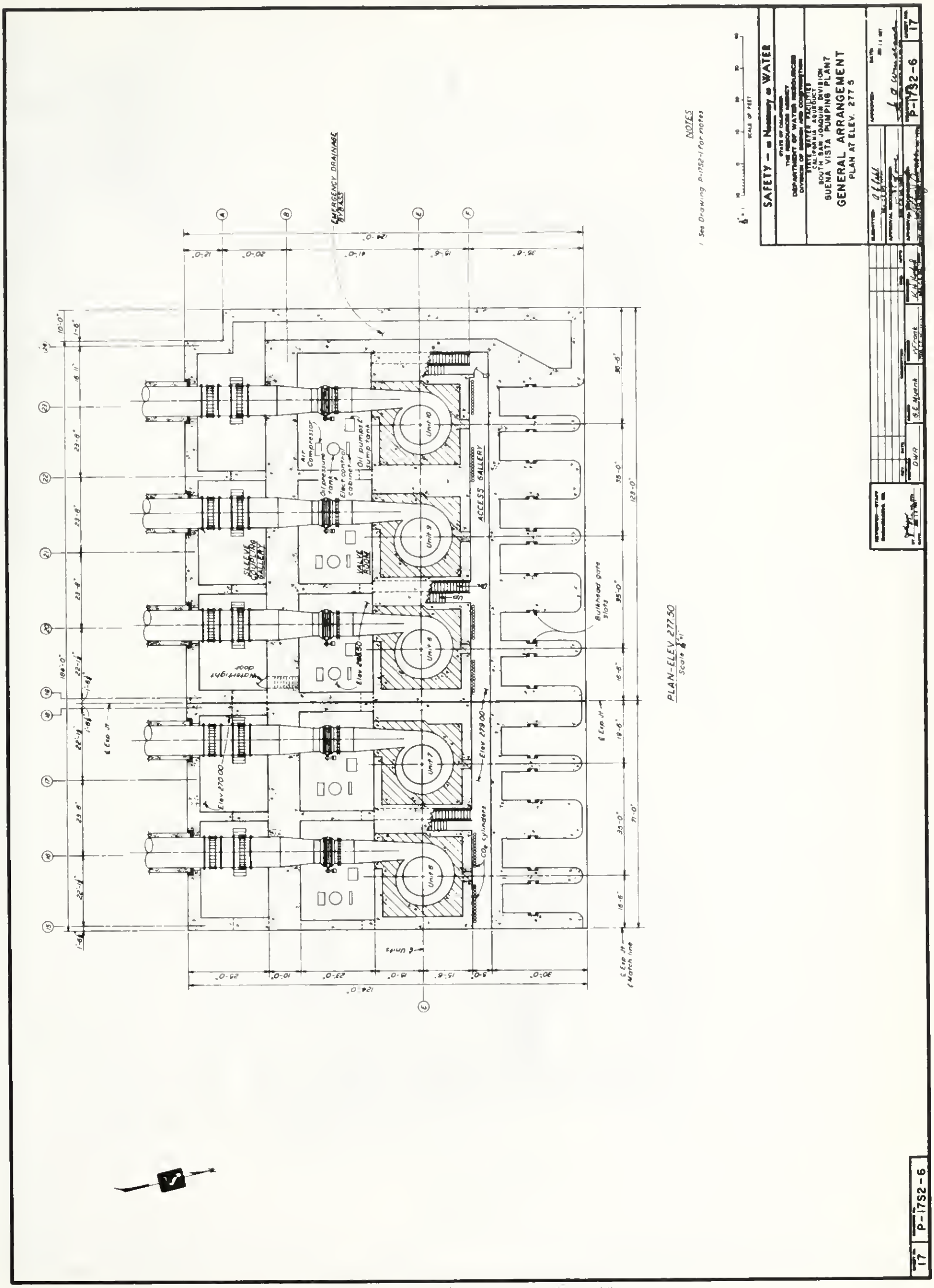

Figure 463. Plan at Elevation 277.5—Buena Vista

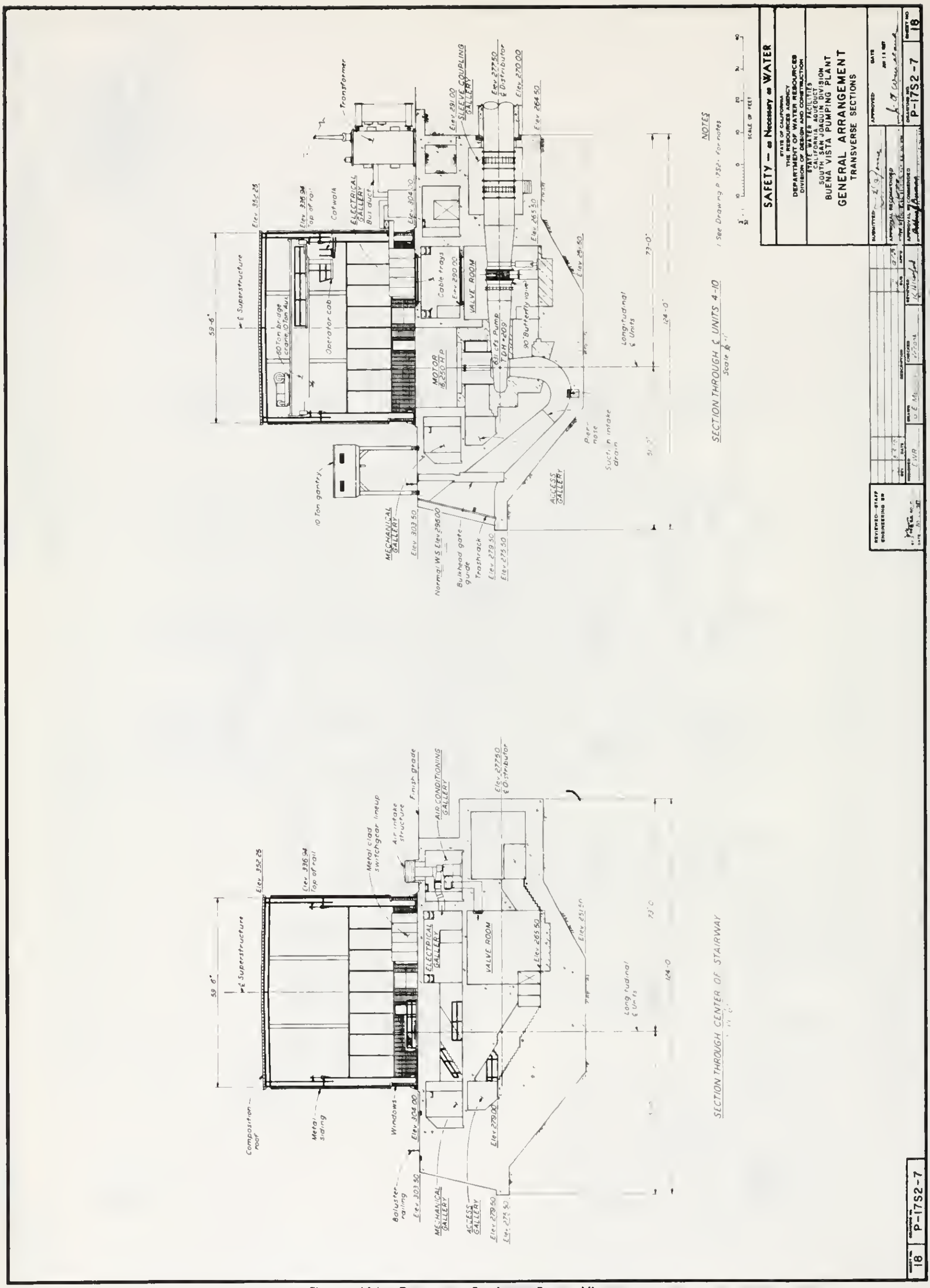

Figure 464. Transverse Sections—Buena Vista

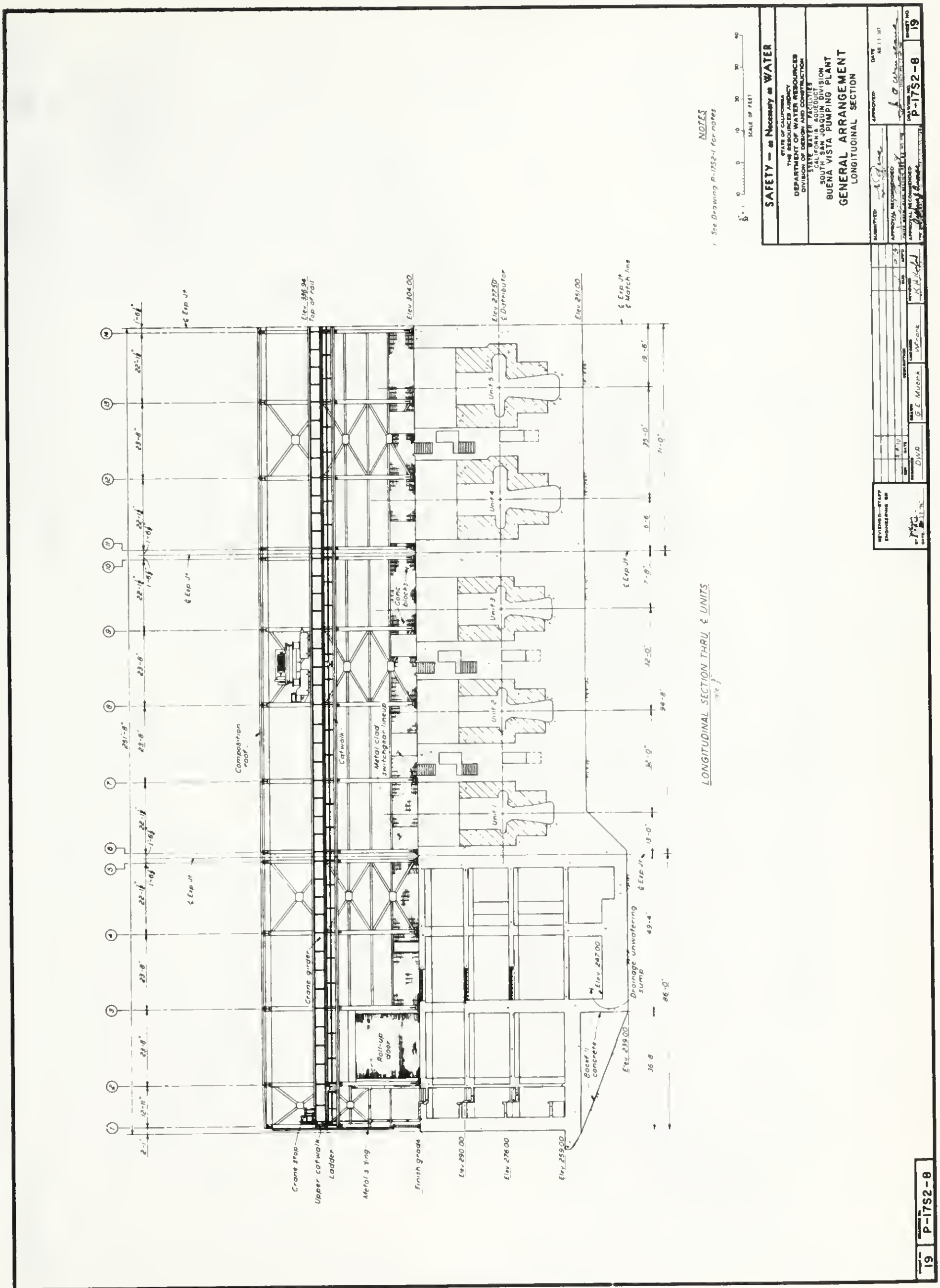

Figure 465. Longitudinal Section Units Nos. 1 Through 5—Buena Vista

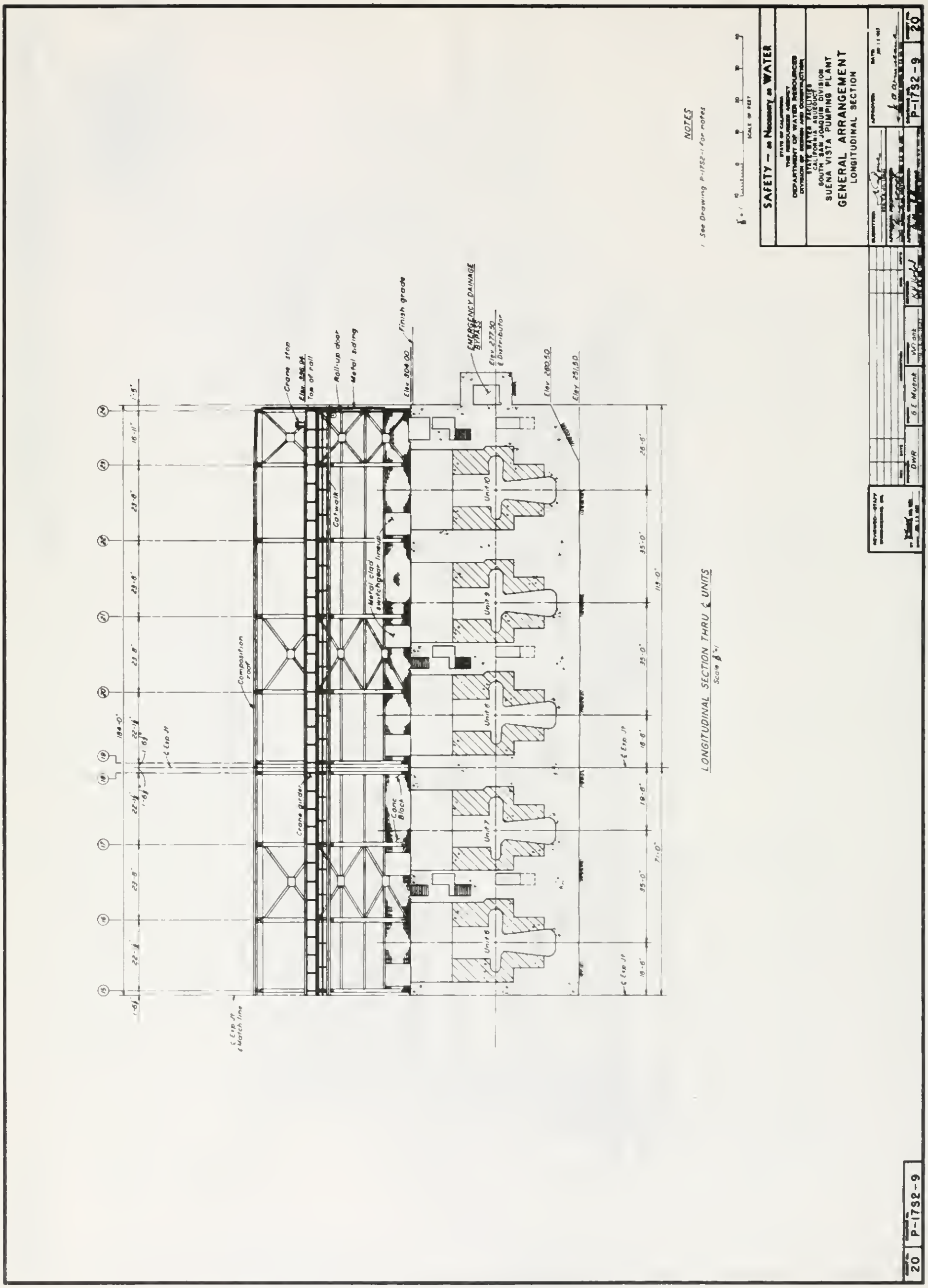

Figure 466. Longitudinal Section Units Nos. 6 Through 10—Buena Vista

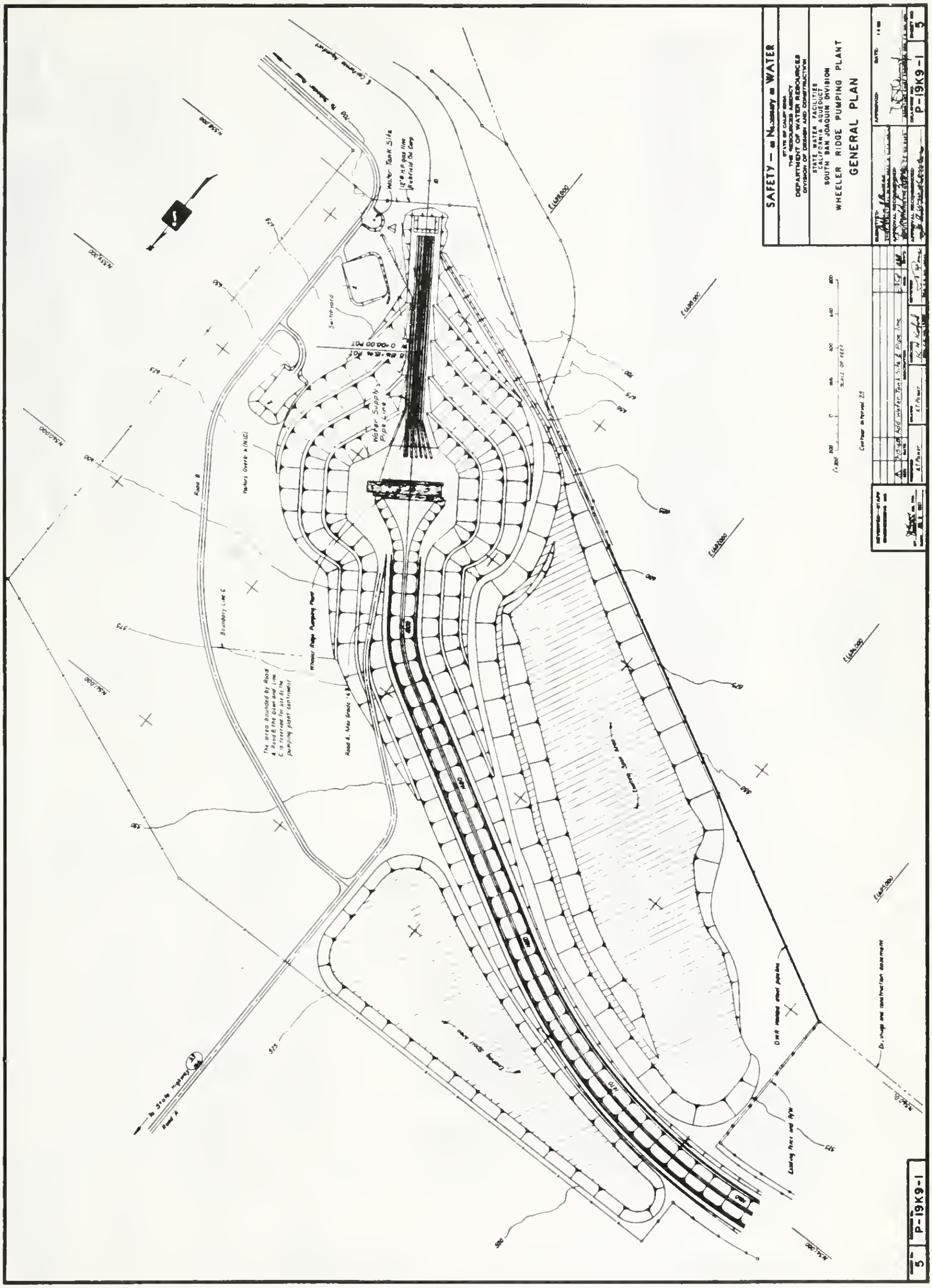

Figure 467. General Plan—Wheeler Ridge

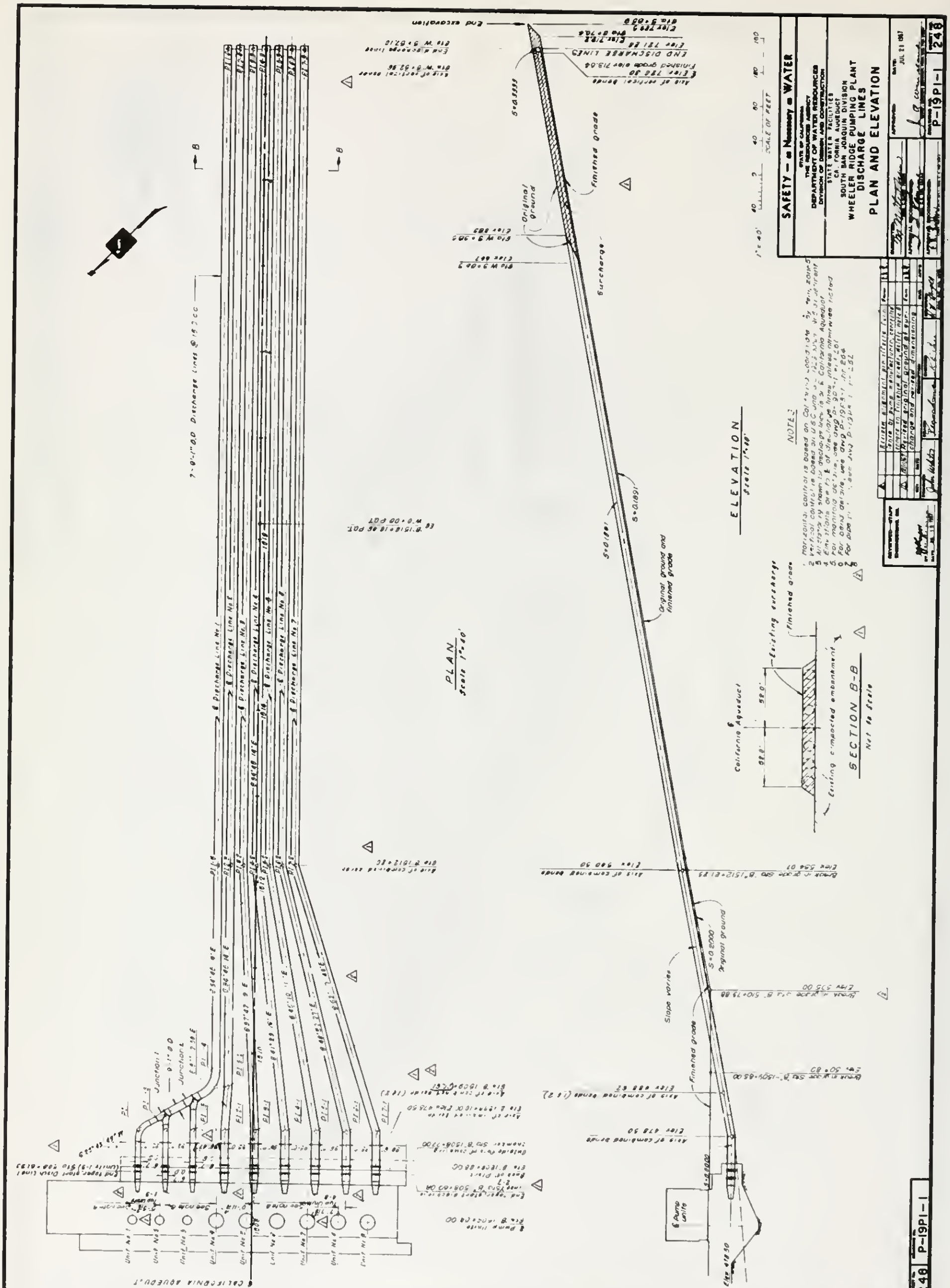

Figure 468. Discharge Lines—Plan and Elevation—Wheeler Ridge

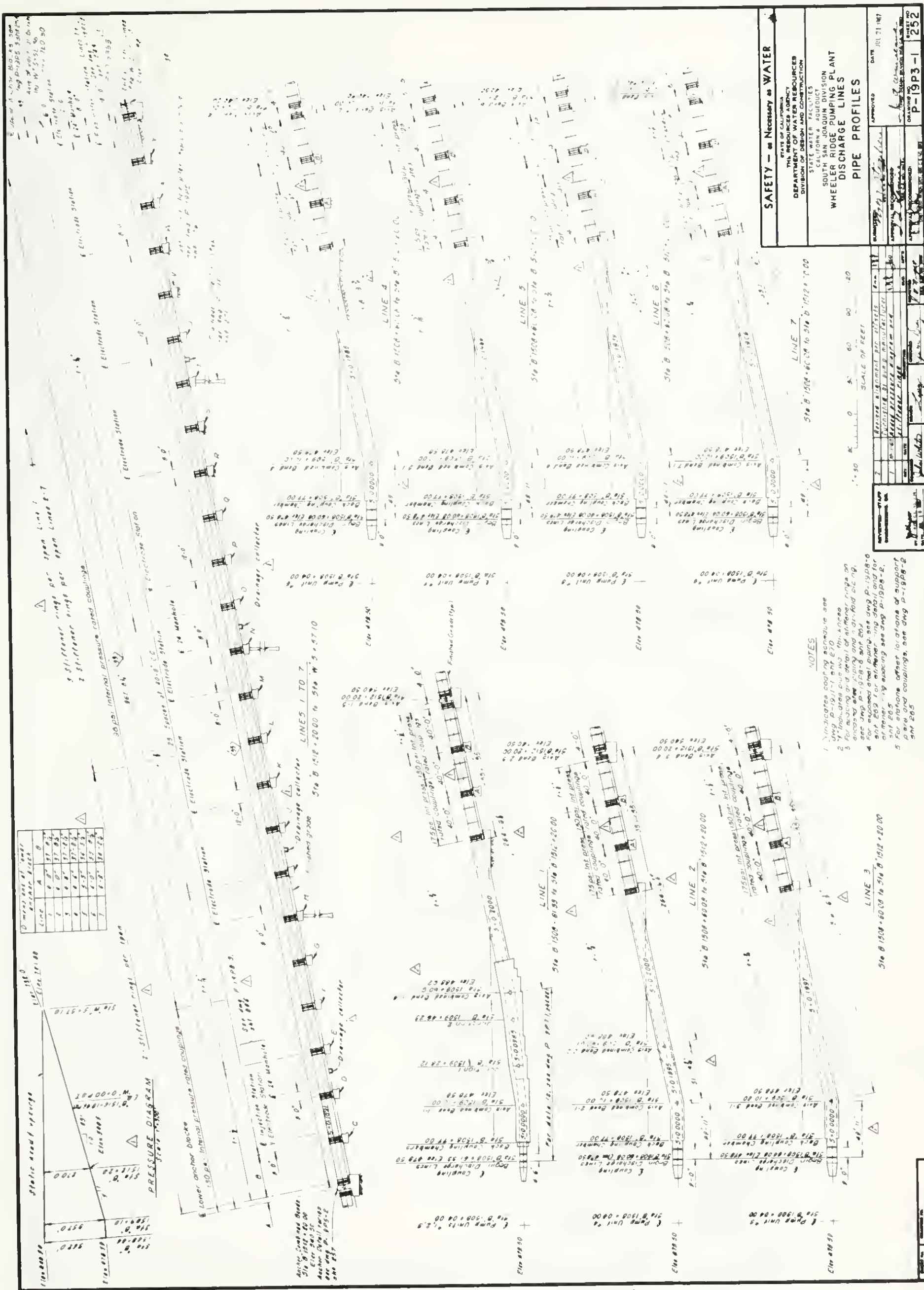

Figure 469. Dischorge Line Profiles—Wheeler Ridge

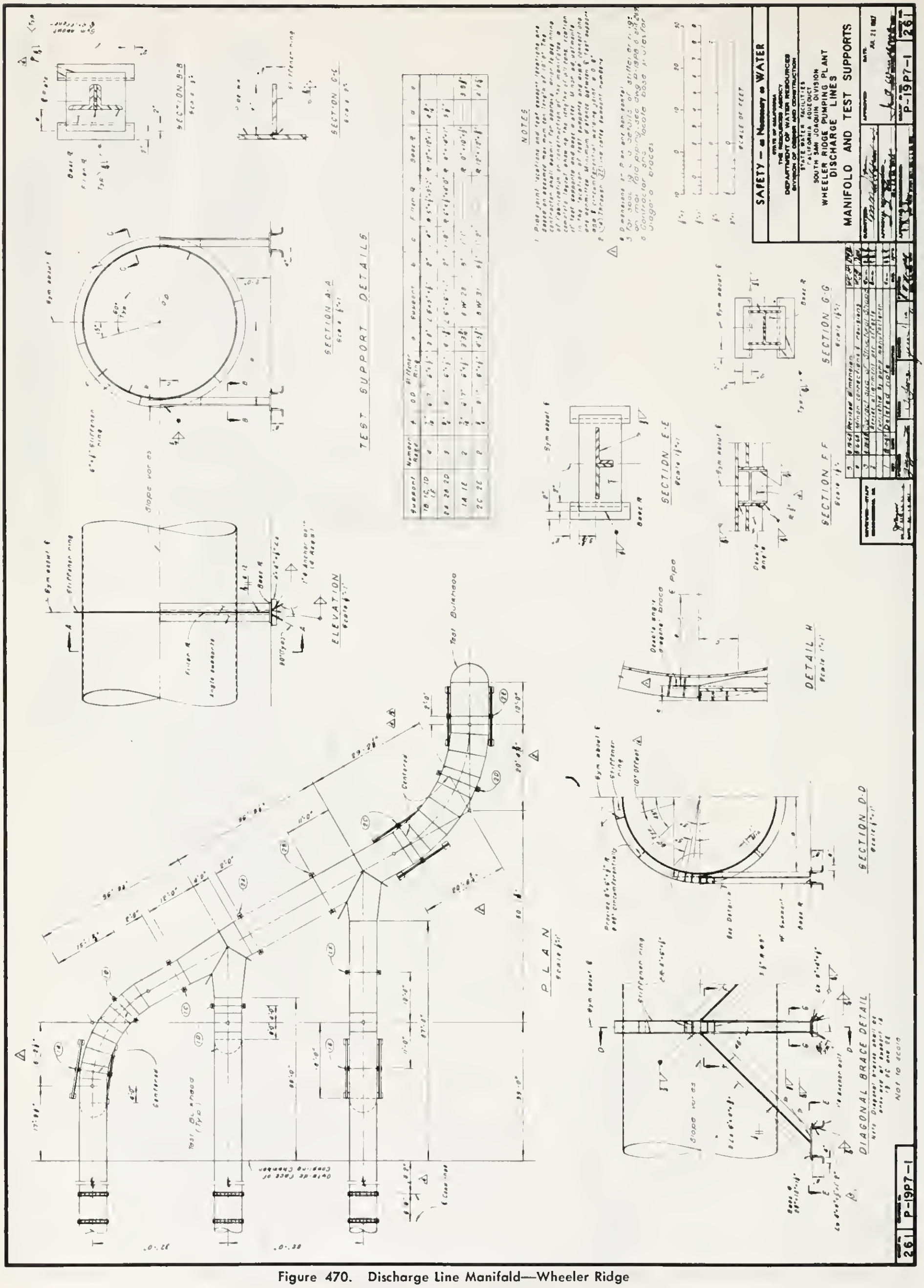

Figure 470. Discharge Line Manifold—Wheeler Ridge

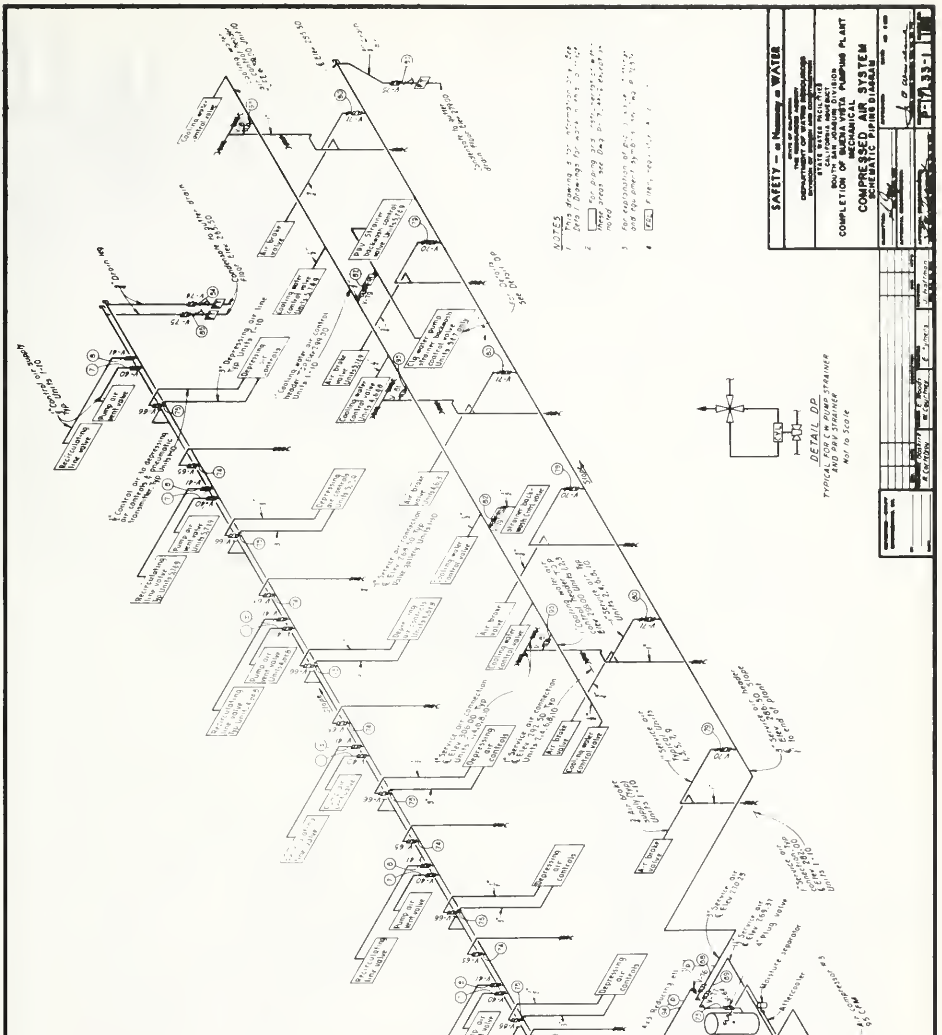

Figure 471. Compressed Air System

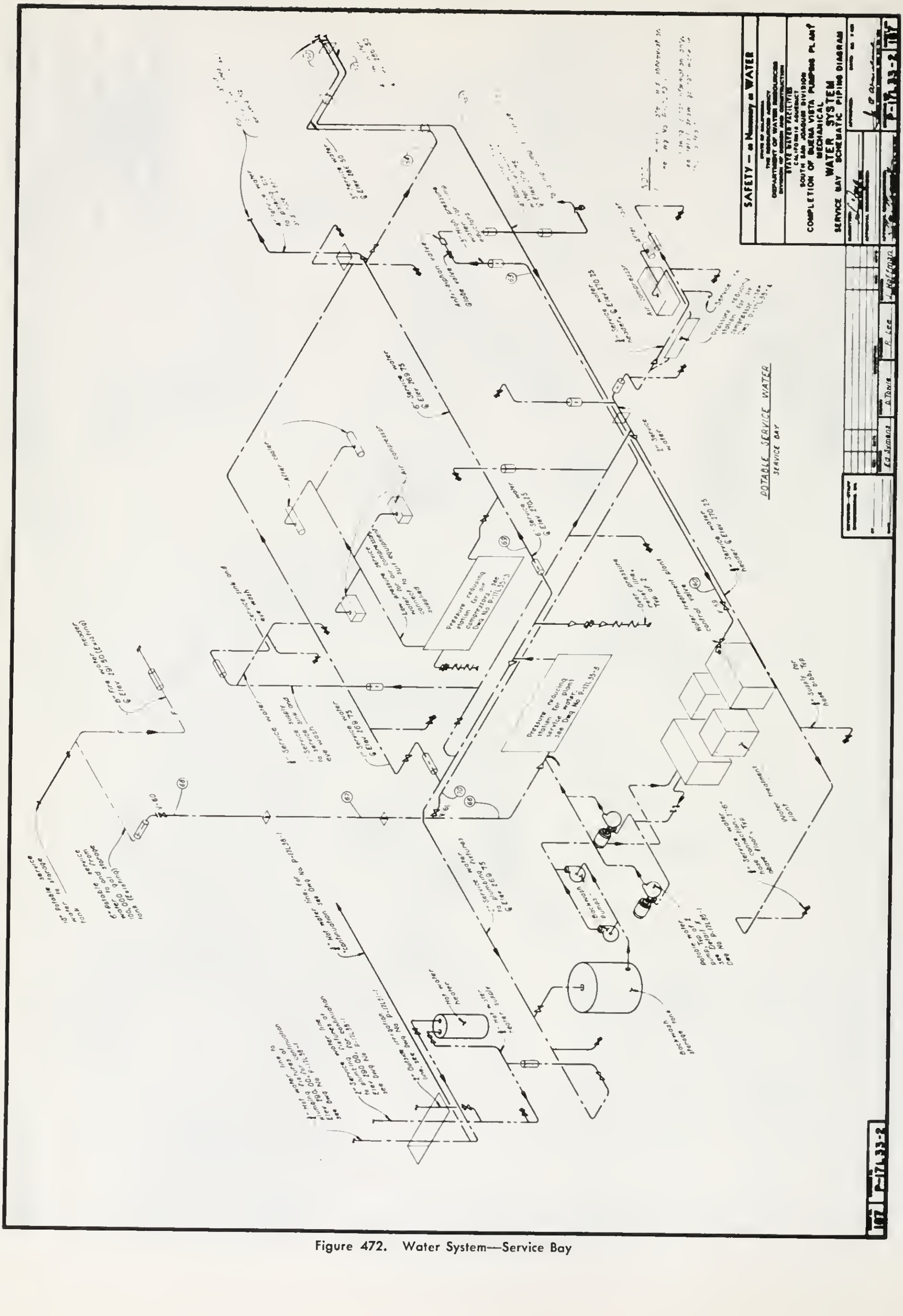

Figure 472. Water System—Service Bay

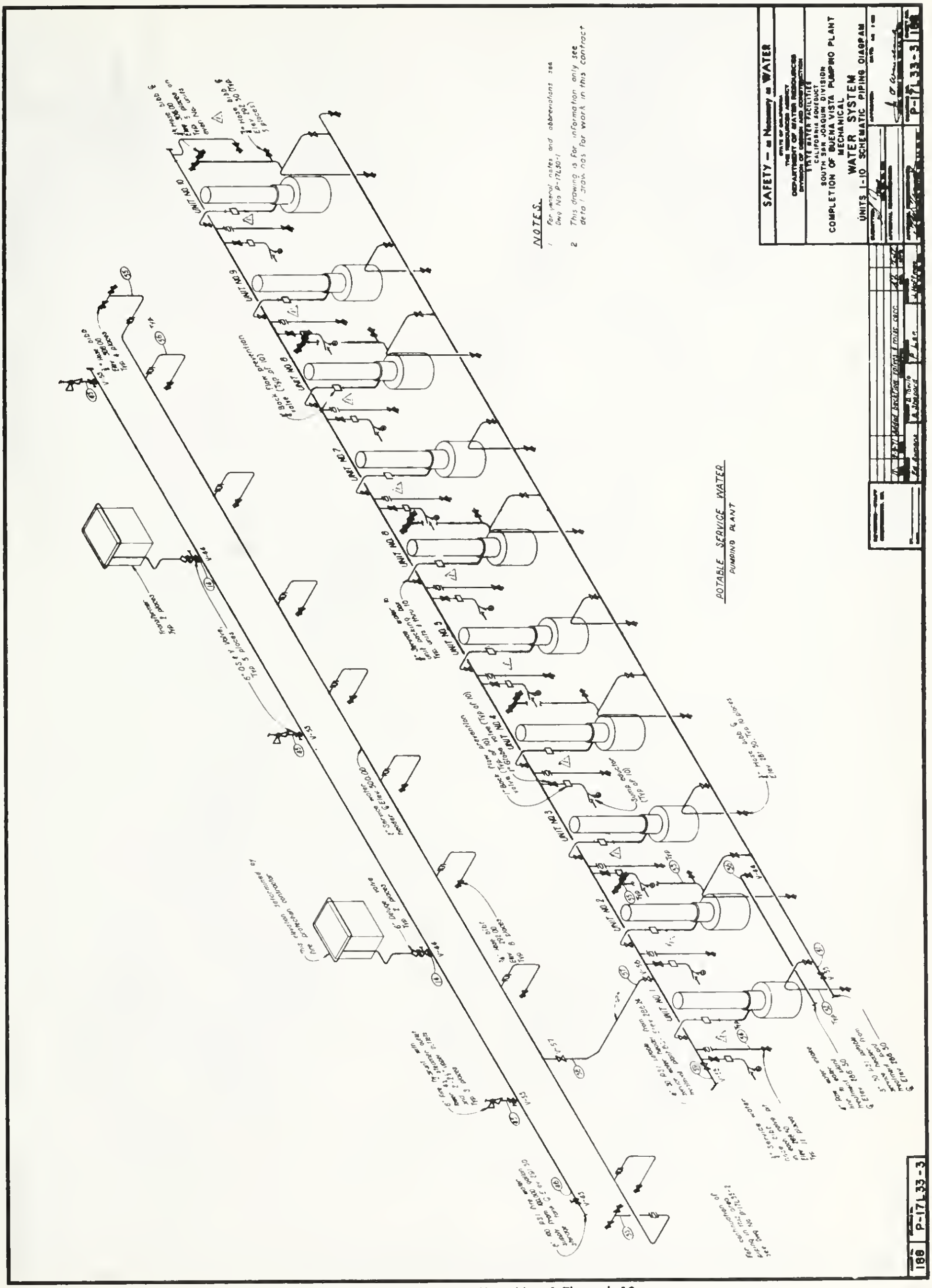

Figure 473. Water System—Units Nos. 1 Through 10

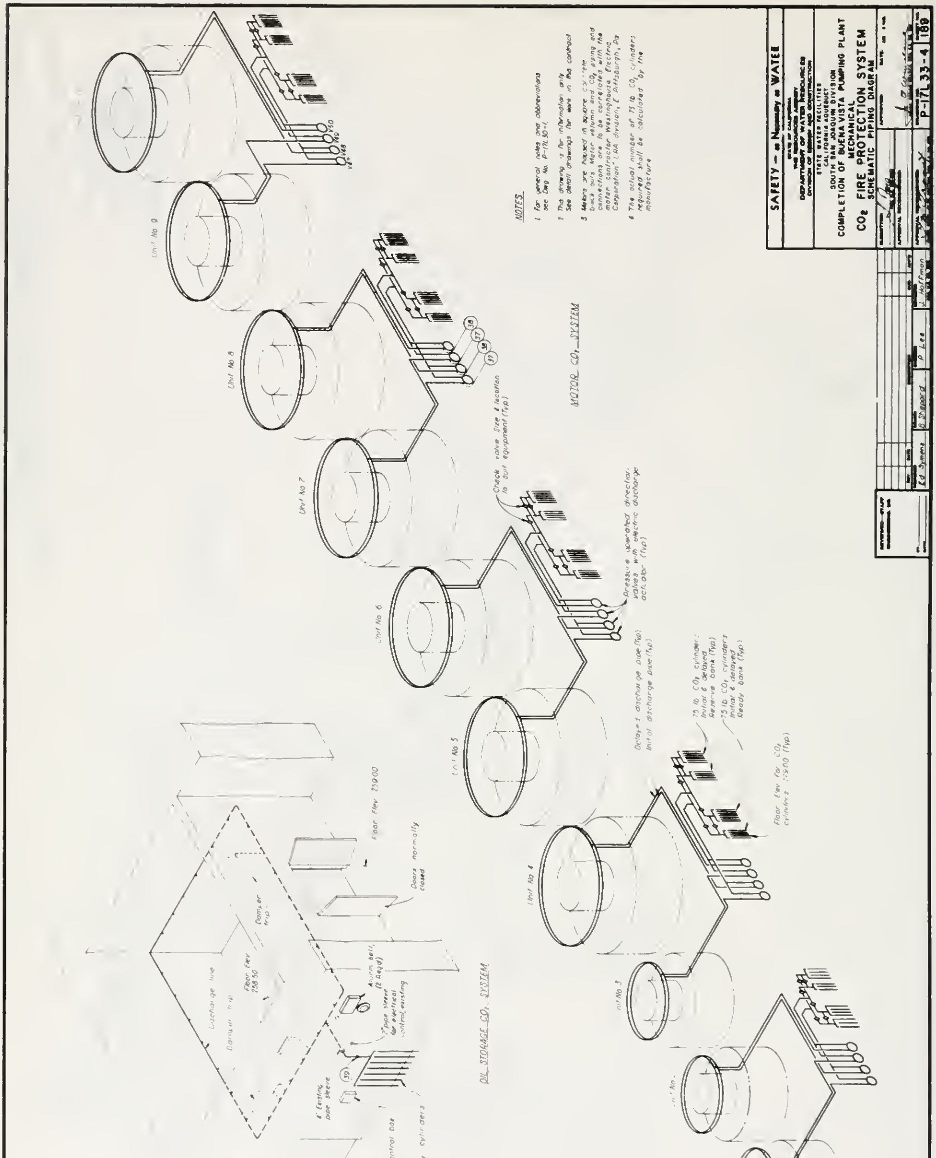

Figure 474. Corbon Dioxide Fire-Protection System

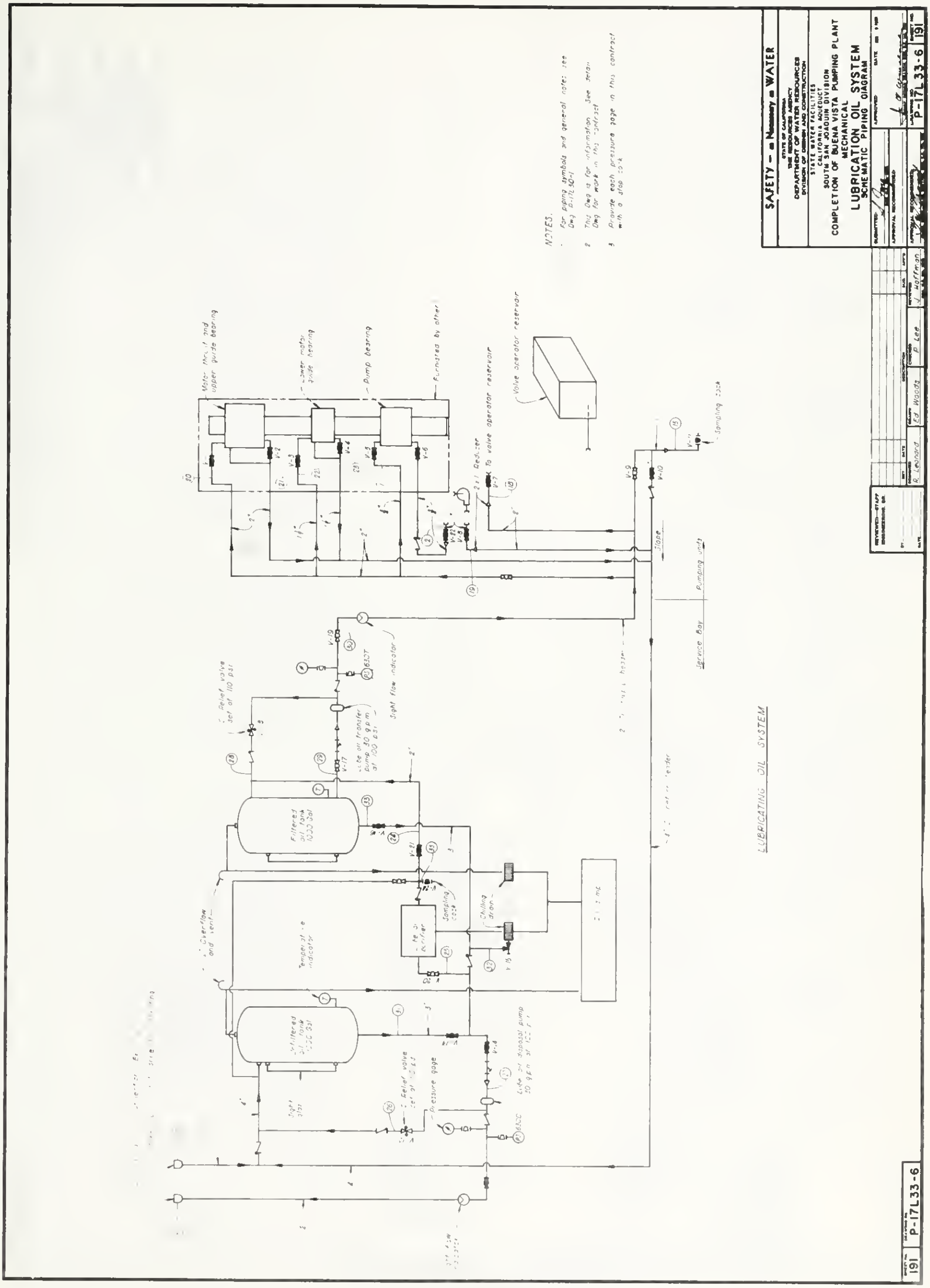

Figure 475. Lubrication Oil System

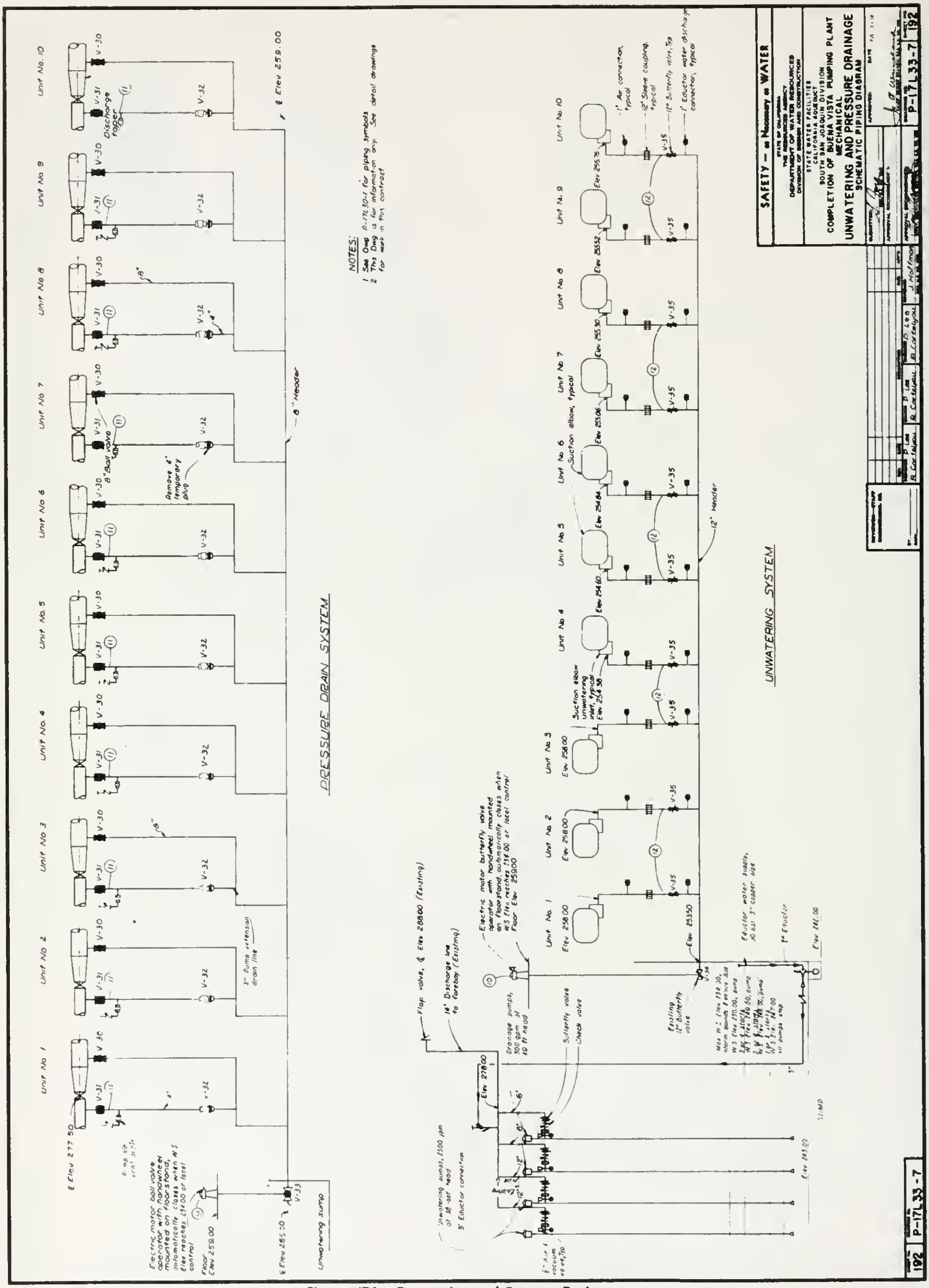

Figure 476. Dewatering and Pressure Drainage

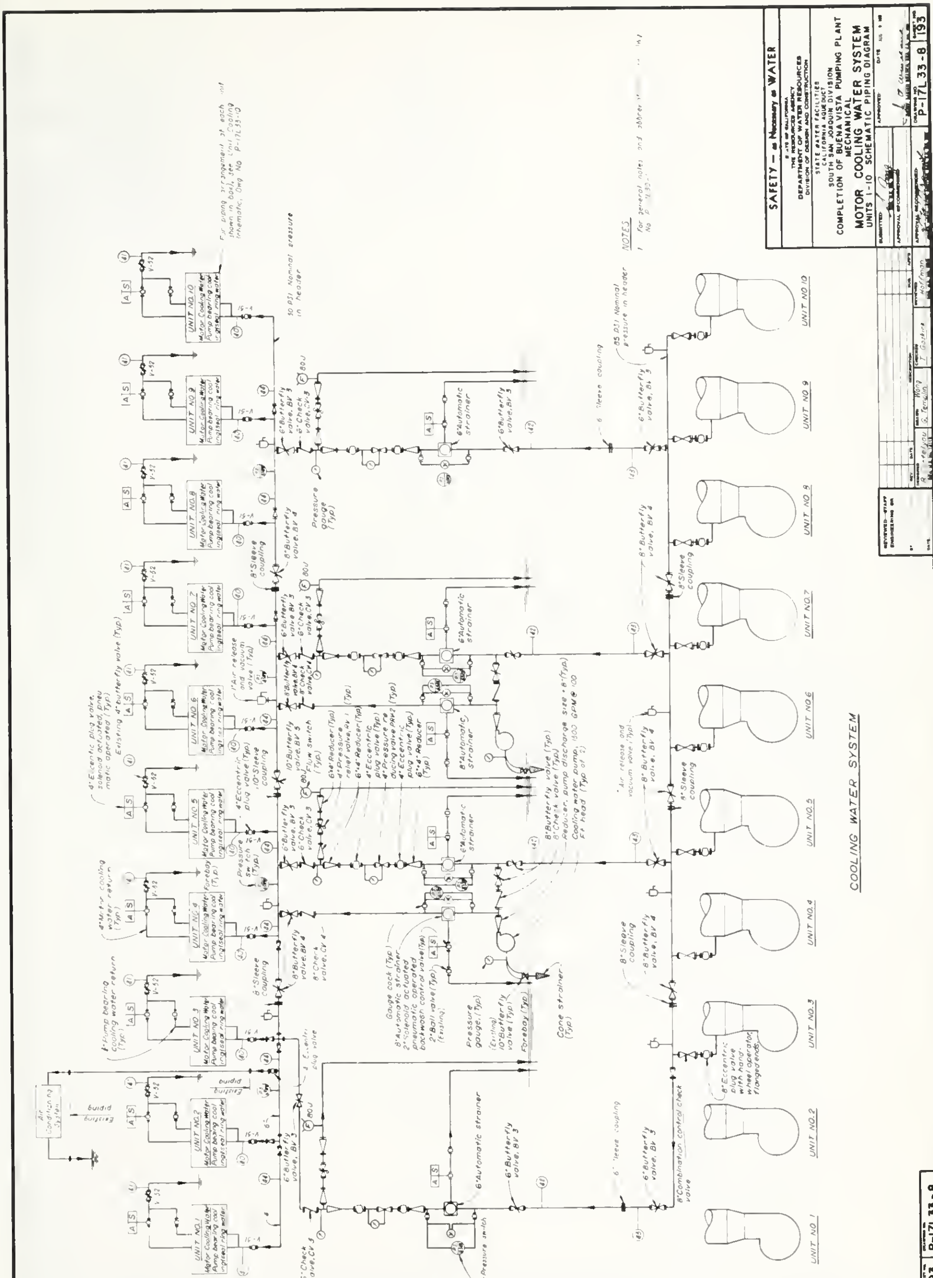

Figure 477. Motor Cooling Water System

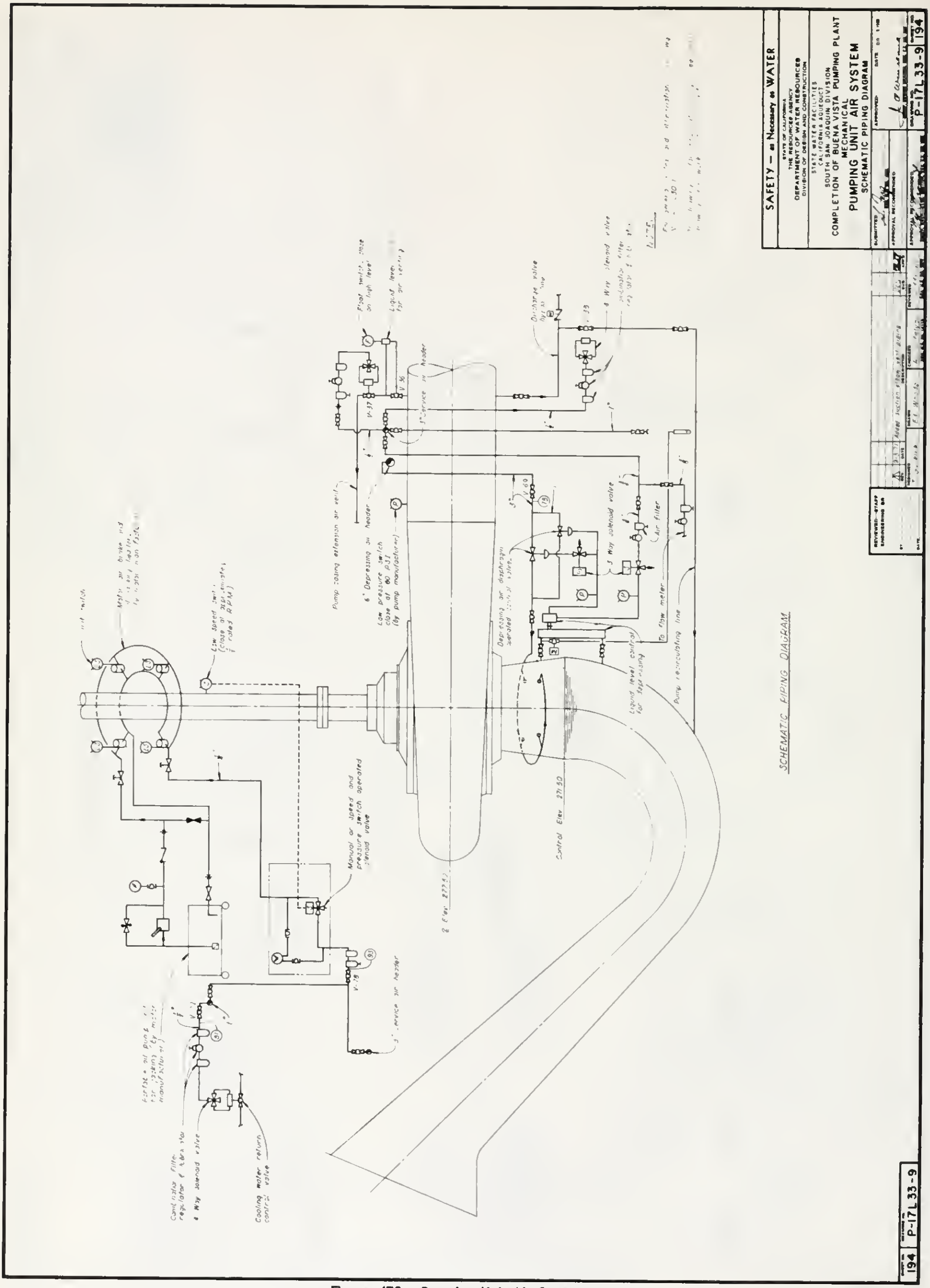

Figure 478. Pumping Unit Air System

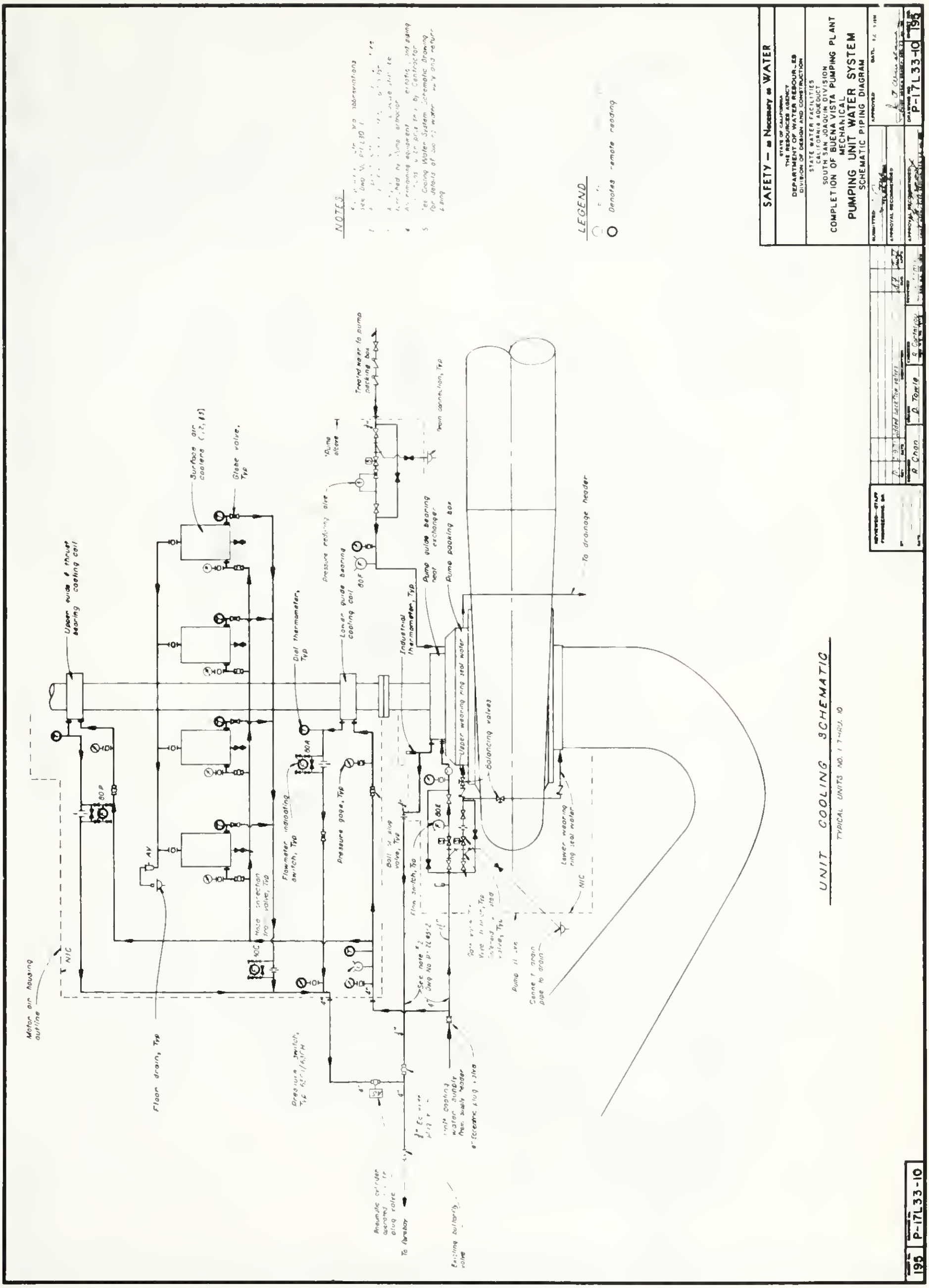

Figure 479. Pumping Unit Water System

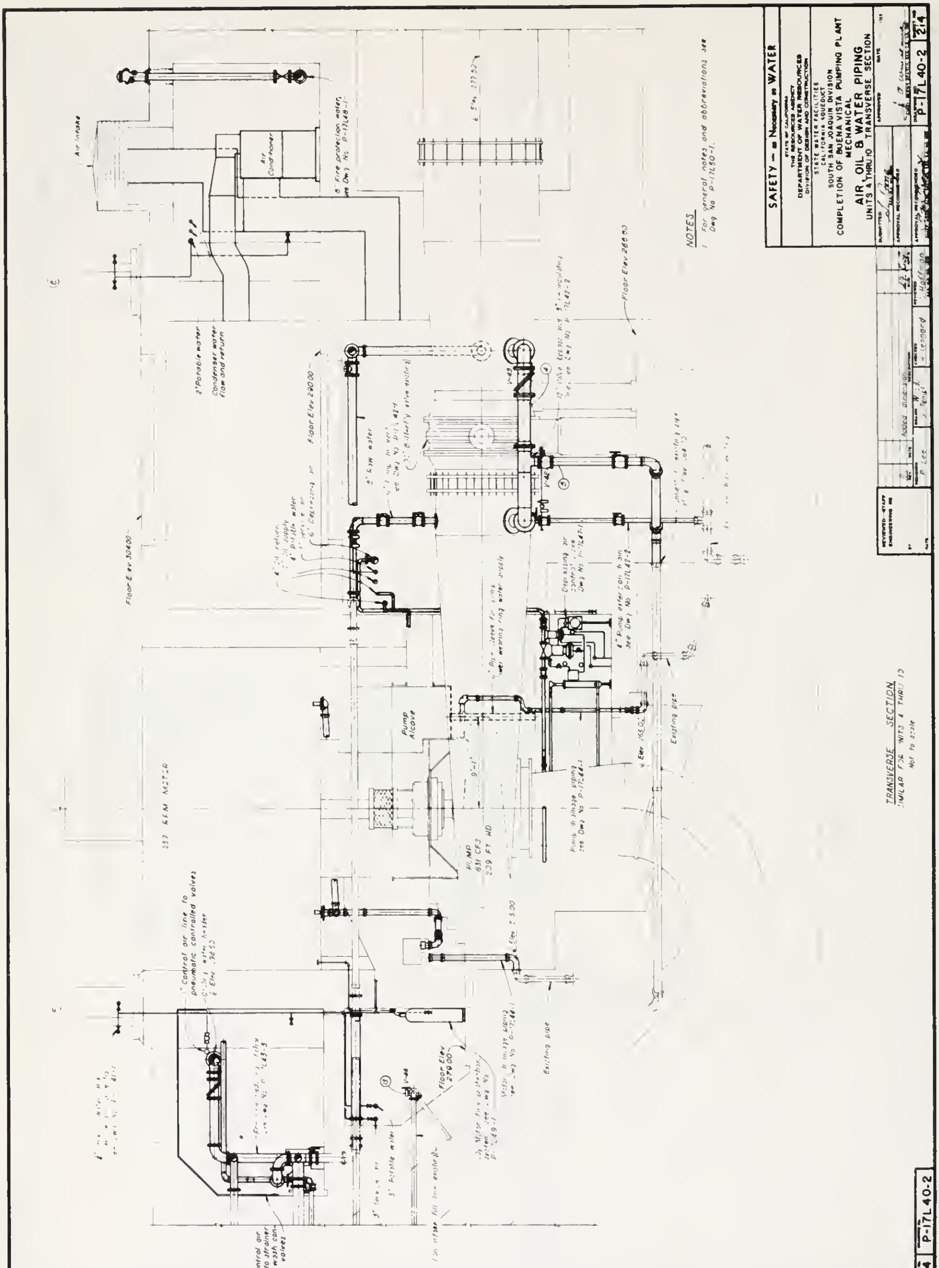

Figure 480. Air, Oil, and Water Piping

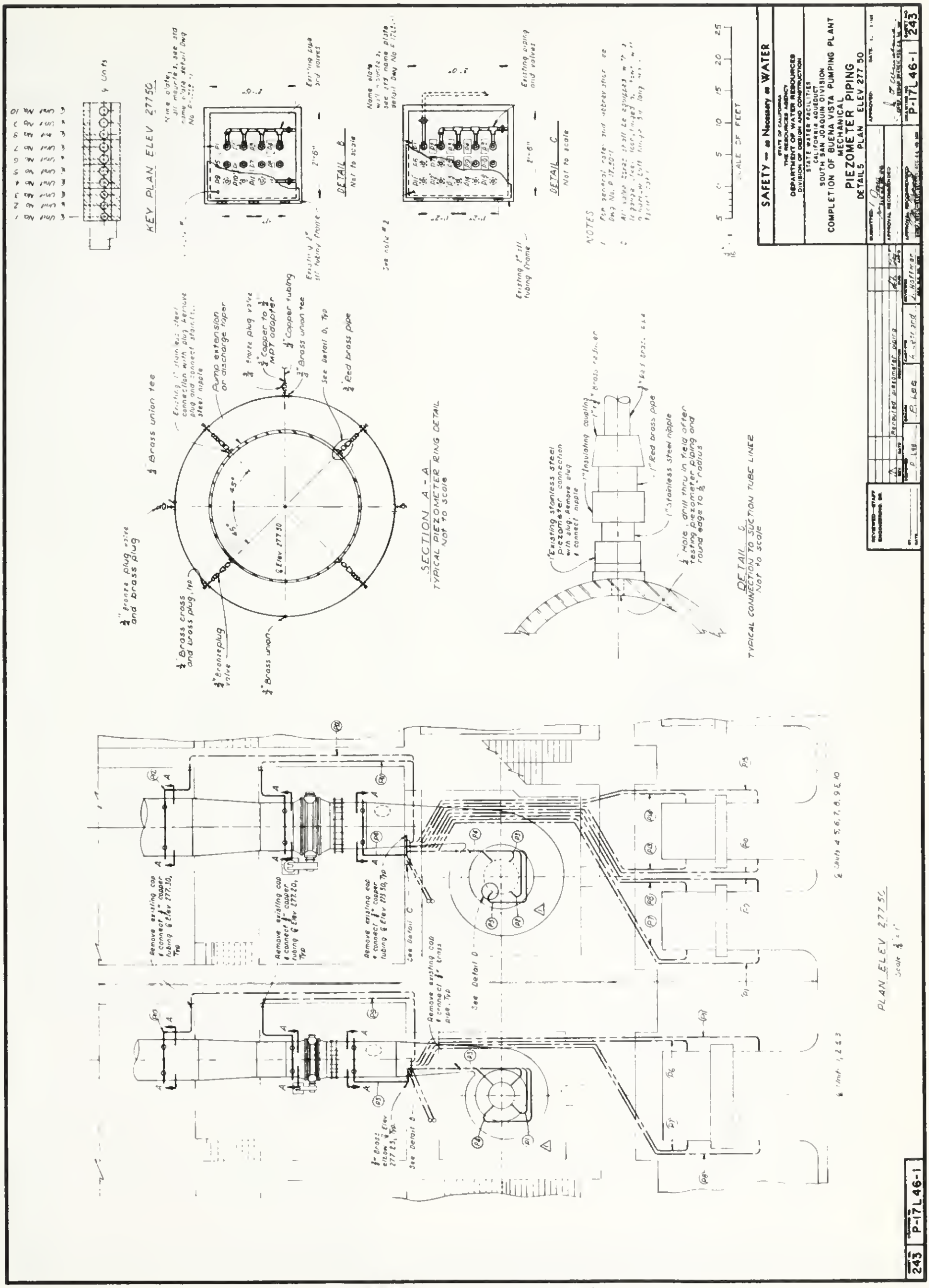

Figure 481. Piezometer Piping—Details

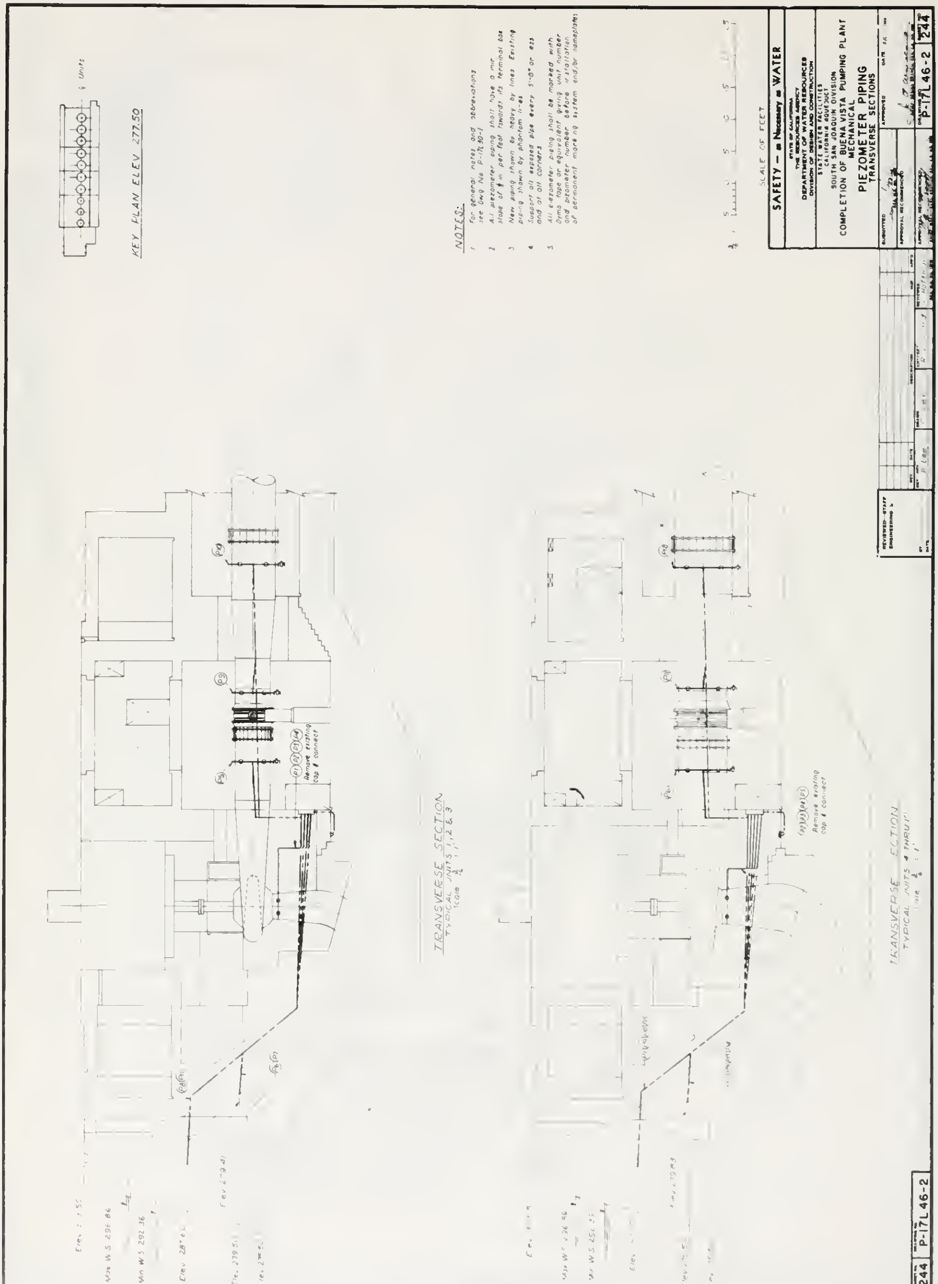

Figure 482. Piezometer Piping—Transverse Sections

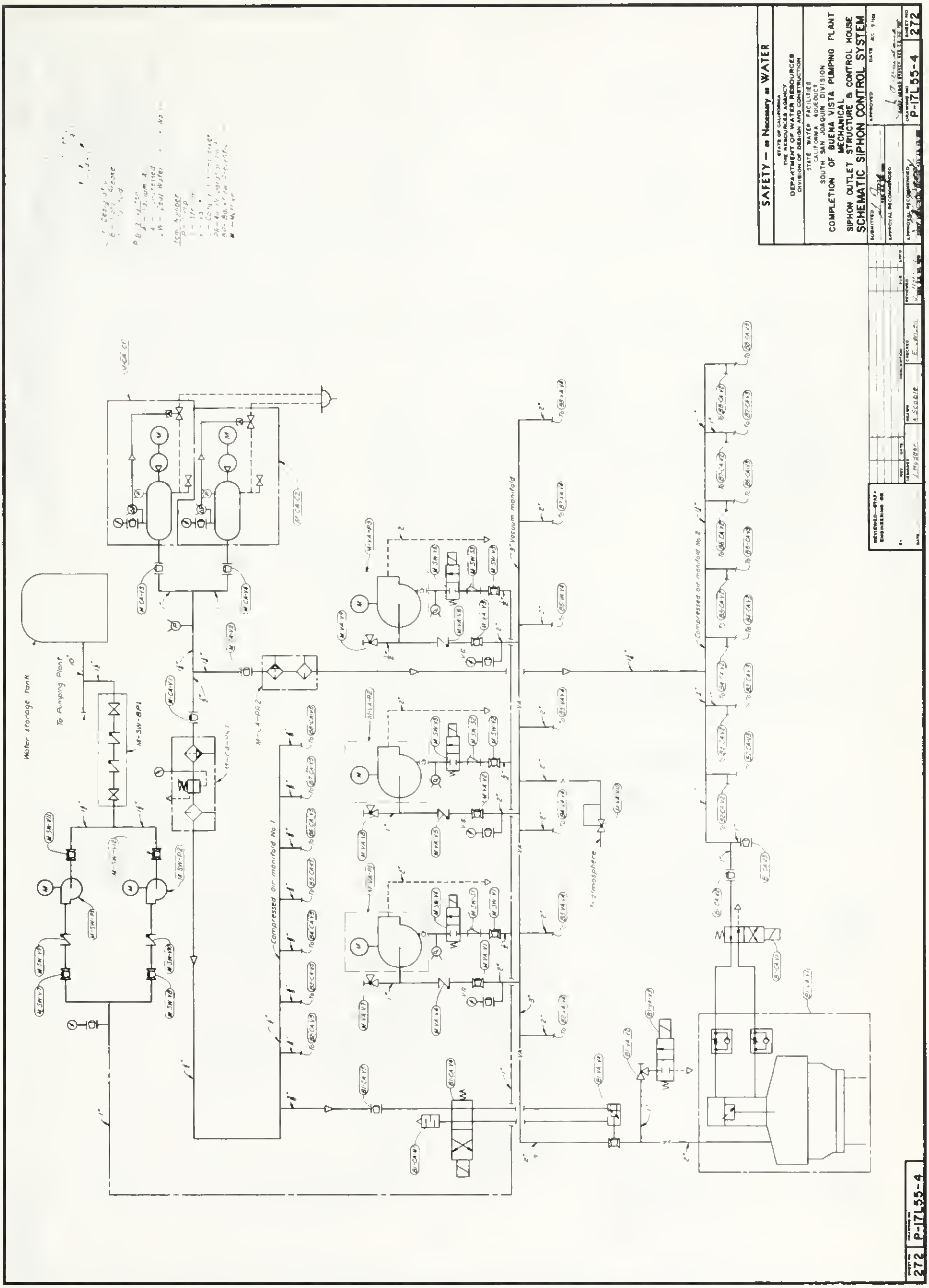

Figure 483. Siphon Cantrol System—Mechonical

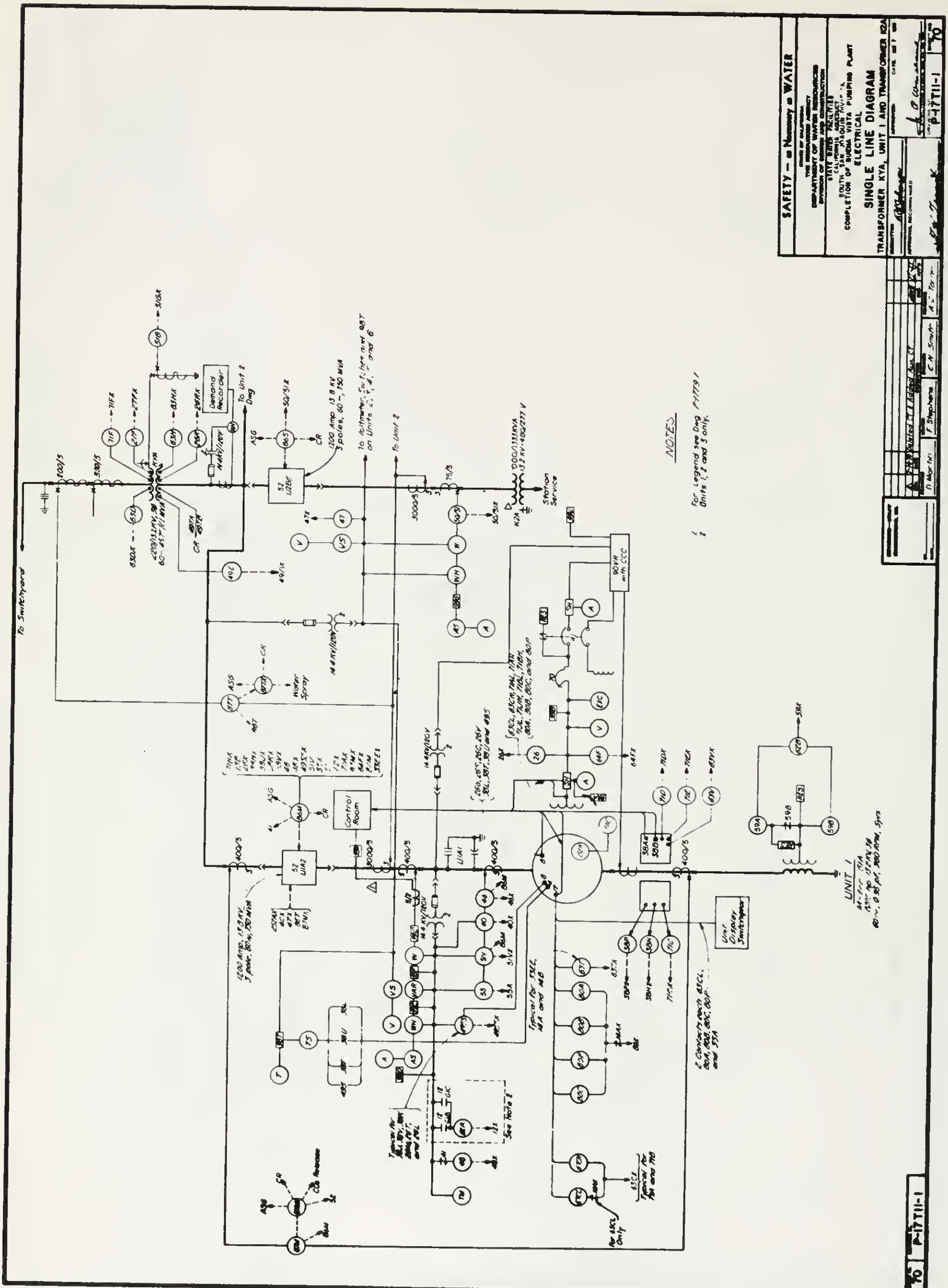

Figure 484. Single-Line Diagram—Unit No. 1—Buena Vista

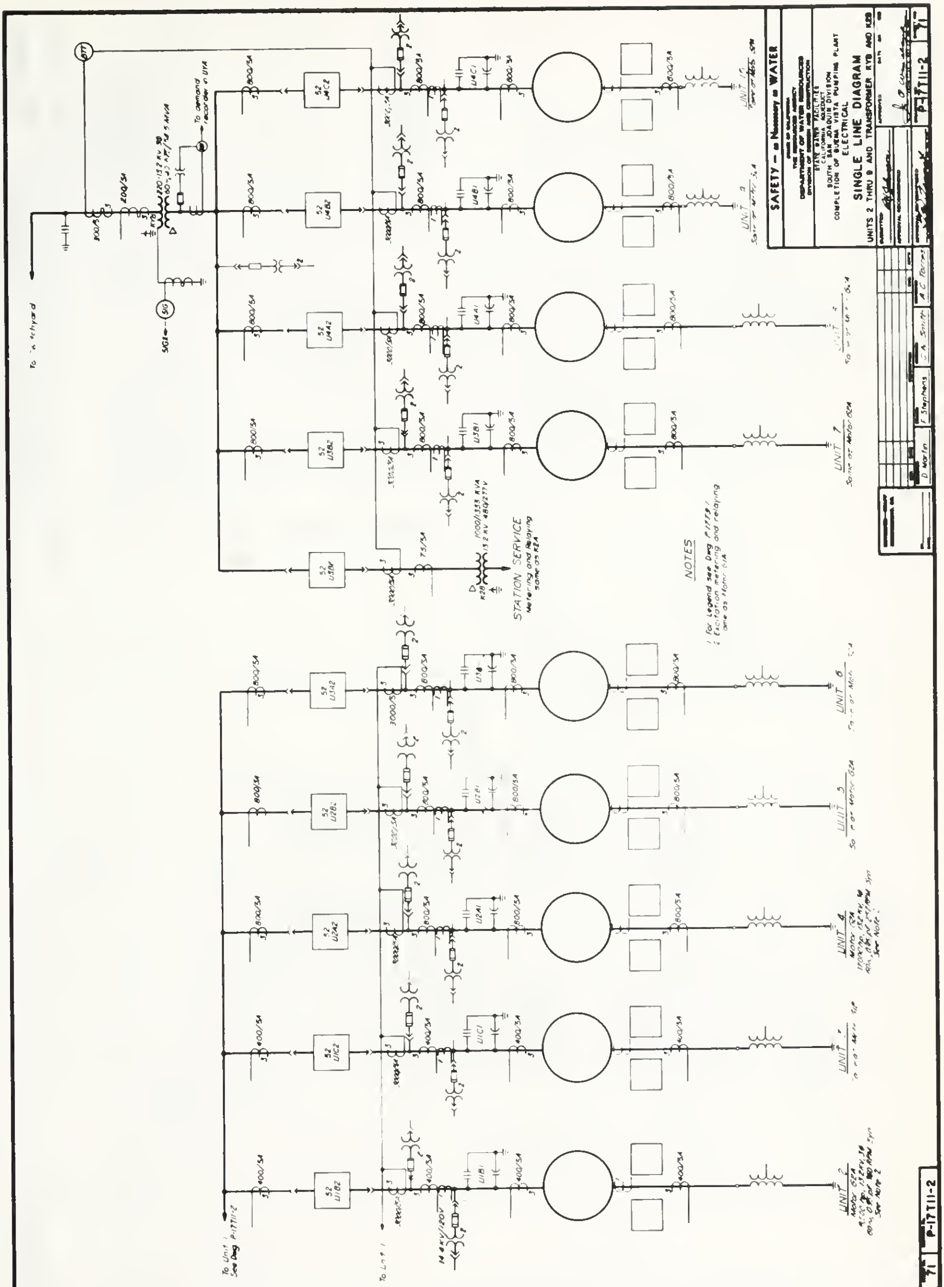

Figure 485. Single-Line Diagram—Units Nos. 2 Through 9—Bueno Vista

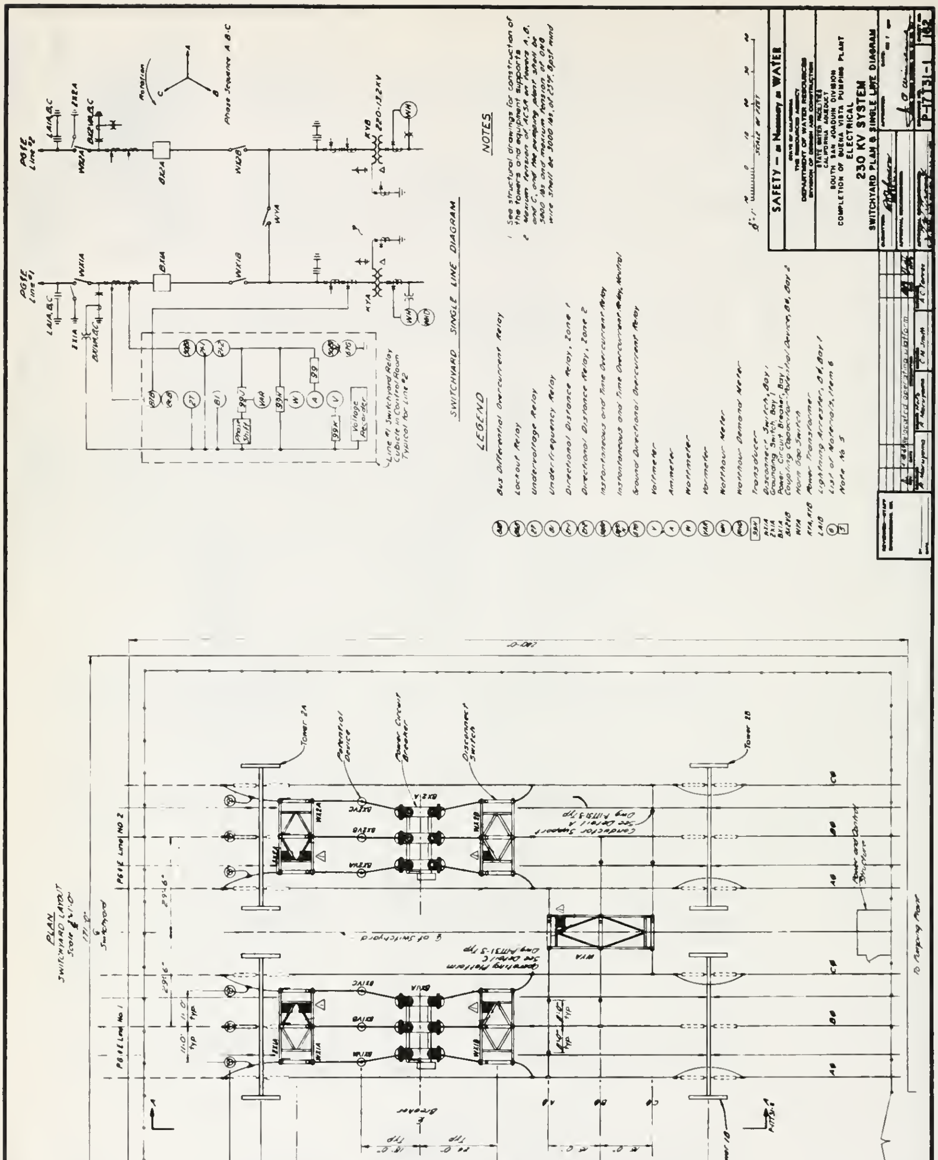

Figure 486. 230-kV Switchyard

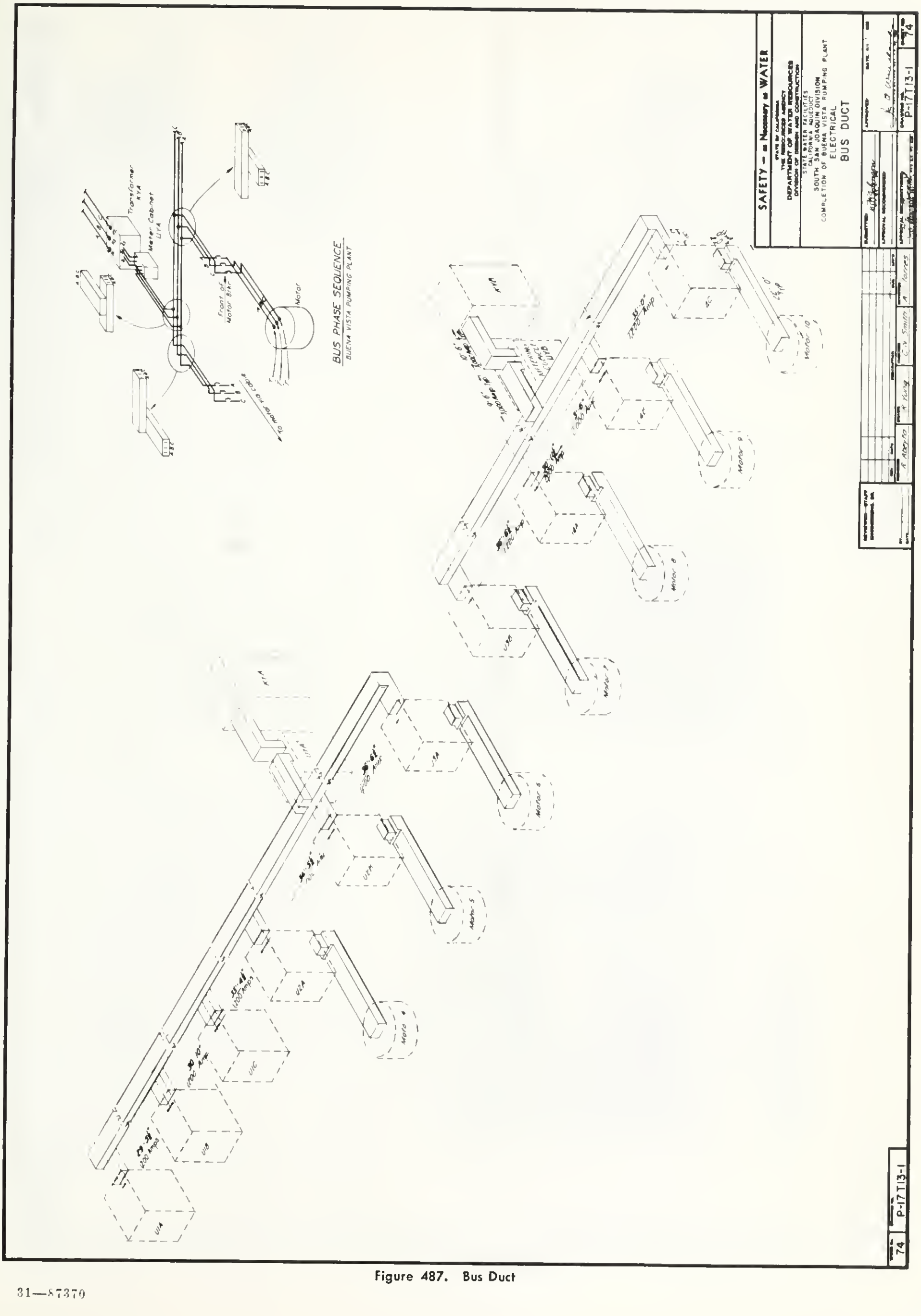

Figure 487. Bus Duct

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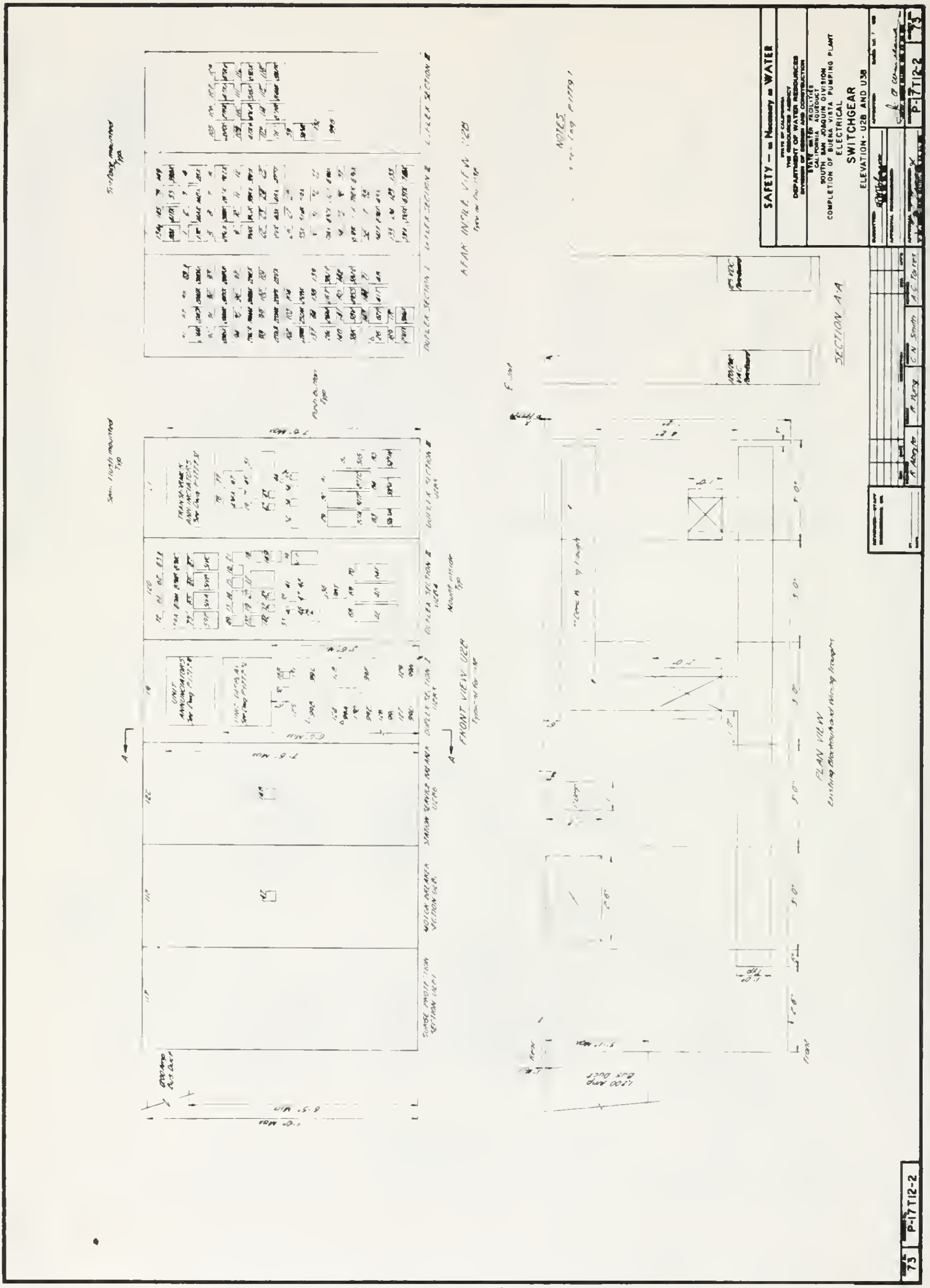

Figure 488. Switchgear

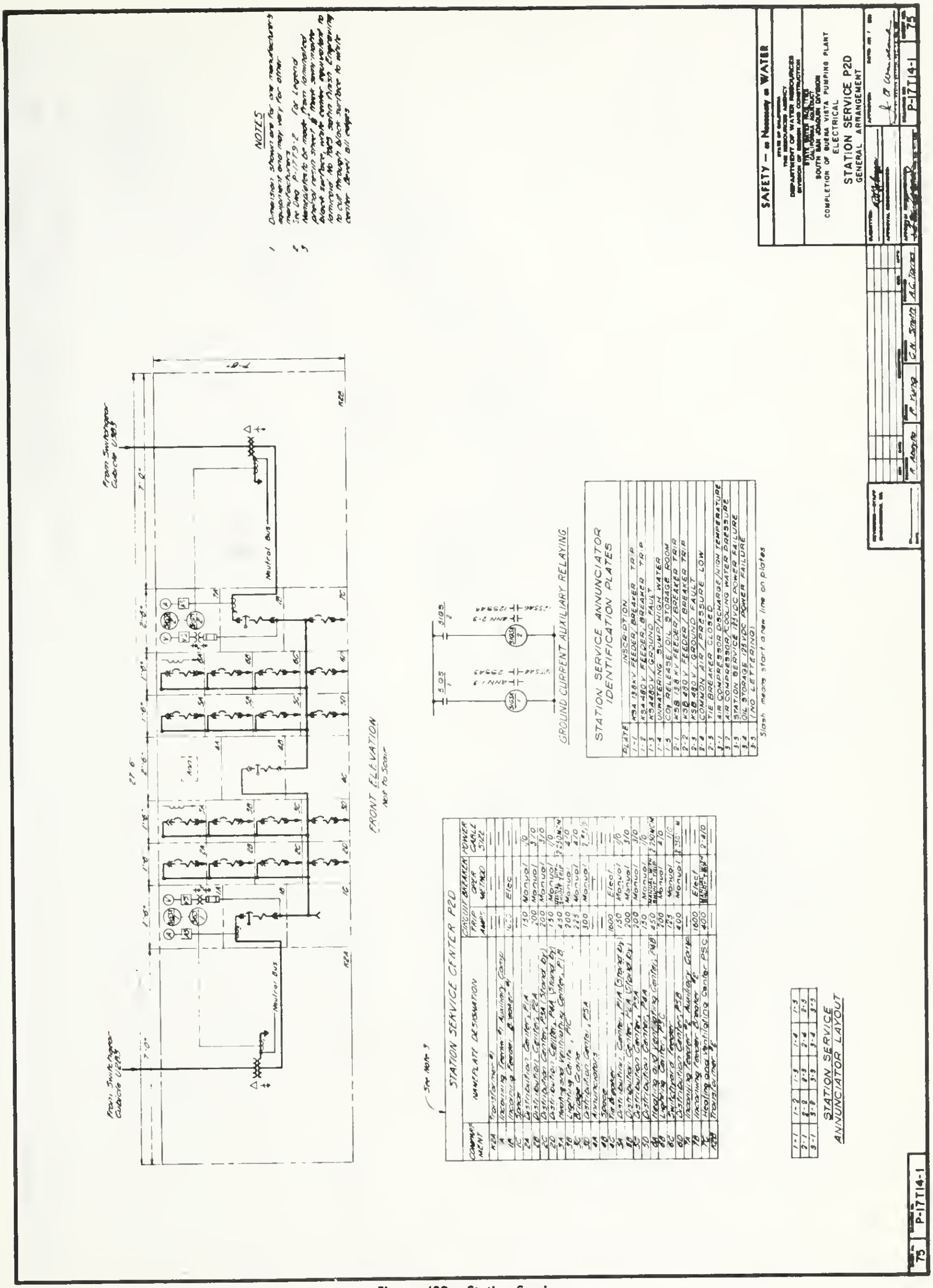

Figure 489. Station Service

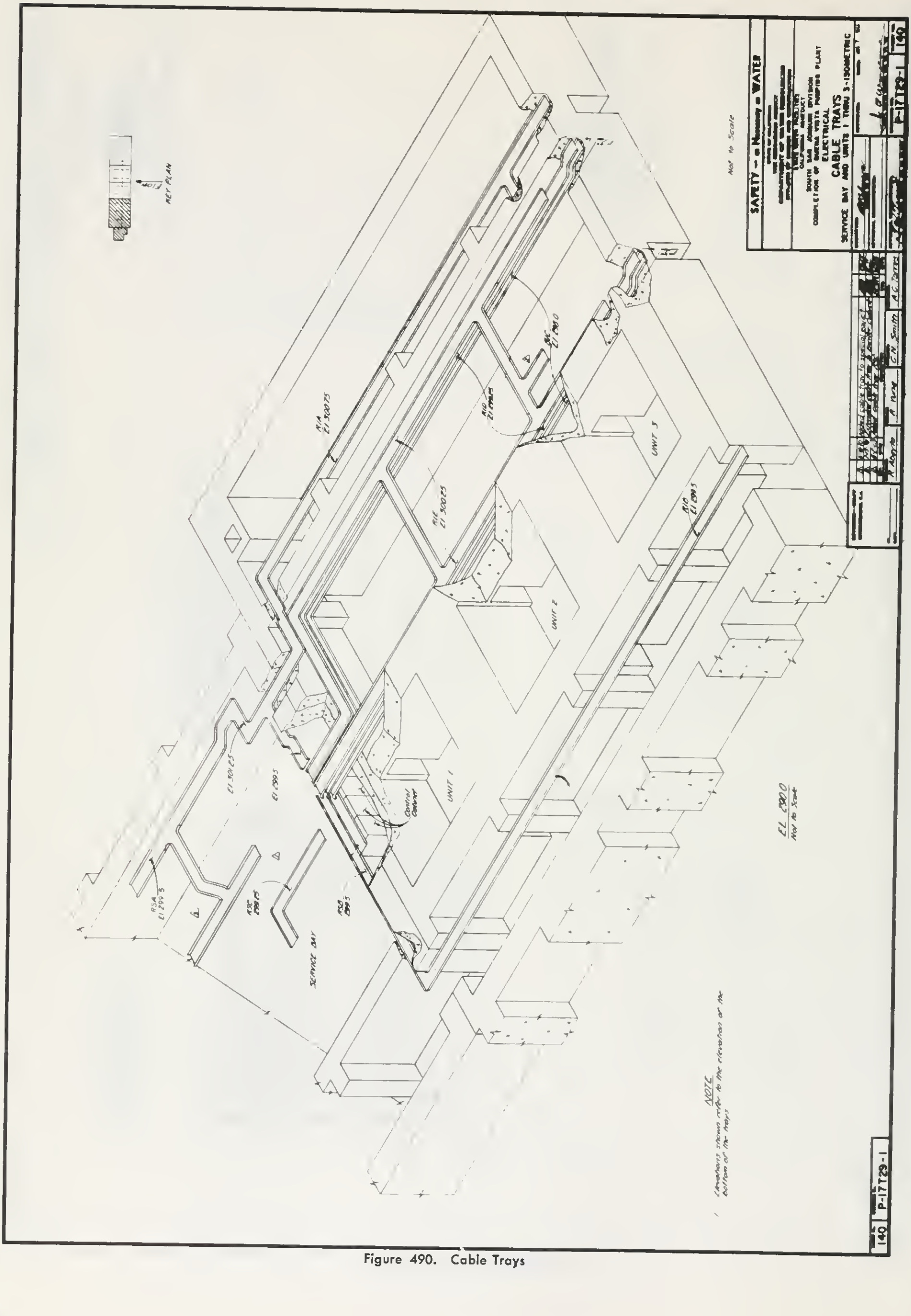

Figure 490. Cable Trays

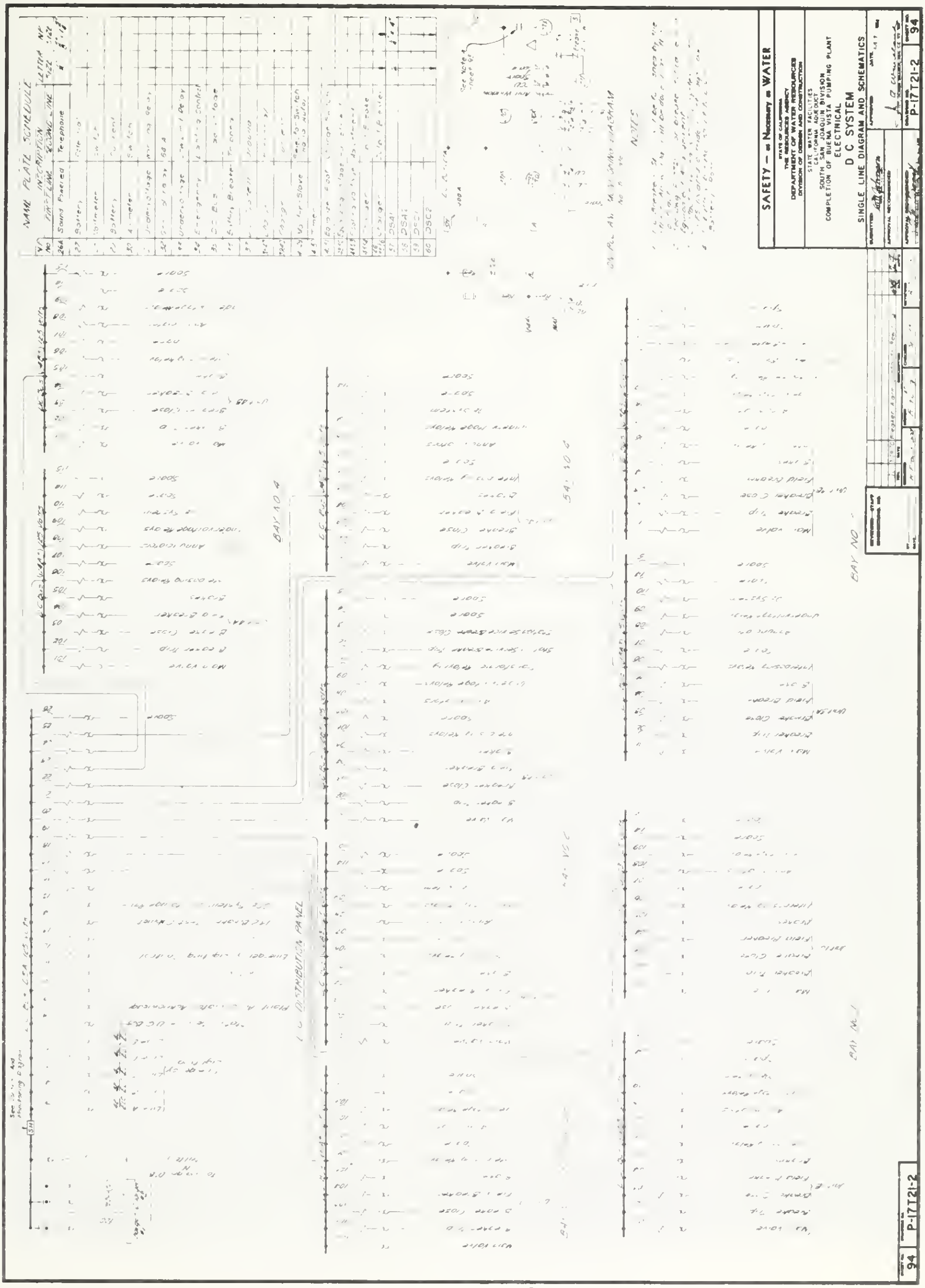

Figure 491. Direct-Current System

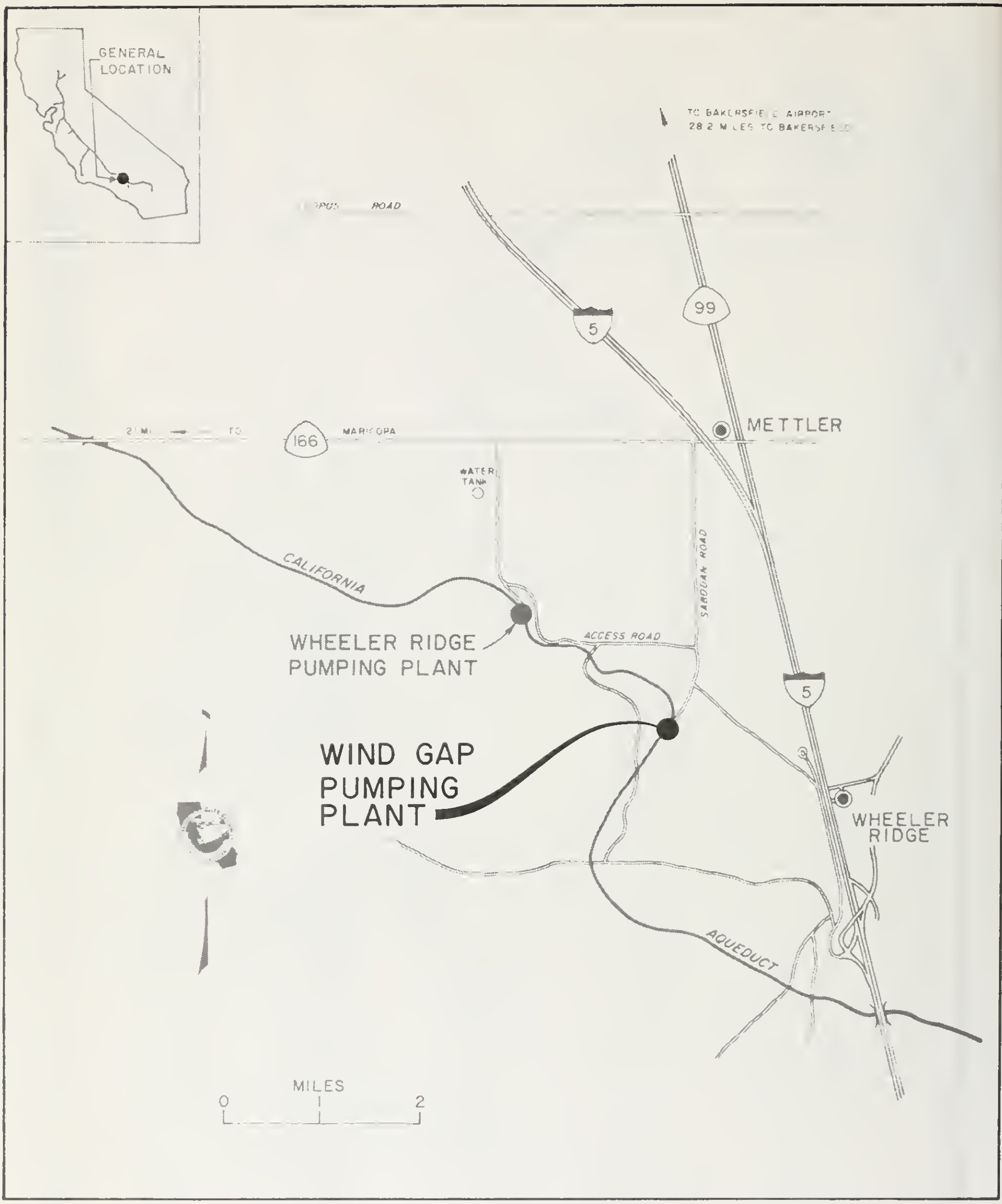

Figure 492. Location Map—Wind Gap Pumping Plant

CHAPTER XII. WIND GAP PUMPING PLANT

General

Location

Wind Gap Pumping Plant is located approximately 24 miles south of Bakersfield. It is west of U.S. Highway 99 and south of Interstate Highway 5, about 4 miles south of the community of Mettler. Access to the plant is from an extension of Sabodan Road, a county road running south from State Highway 166.

The plant is approximately 1.6 miles downstream from Wheeler Ridge Pumping Plant (Figures 492 and 493).

Purpose

Wind Gap Pumping Plant is an "in-line" plant located in the South San Joaquin Division of the California Aqueduct.

Water discharged from this plant flows by gravity to the A. D. Edmonston Pumping Plant.The normal static lift is 518 feet.

Description

This plant (Figures 494 and 495) is constructed in a deep bowl, the bottom of which was excavated approximately 110 feet below original ground level. The excavation is approximately 640 feet wide and 530 feet long at the bottom.

Wind Gap Pumping Plant facilities consist of the plant structure; nine pumping units; a 230-kV switchyard; a transformer yard; three 12-foot - 6-inch-diameter and one 9-foot - 6-inch-diameter steel discharge lines aboveground, approximately 2,000 feet in length; and a siphon outlet structure.

The total design flow of the facility is 4,410 cubic feet per second (cfs). Six pumping units are rated 630 cfs at 524 feet of head, and three units are rated 315 cfs at 524 feet of head. One 315-cfs unit is used as a standby.

The three smaller units discharge into a concrete-encased steel manifold and a single 9-foot - 6-inch-diameter discharge line. The six 630-cfs units discharge through three 12-foot - 6-inch discharge lines. Two units are connected by a wye manifold to each discharge line.

Figure 493. Aerial View—Wind Gap Pumping Plant

Figure 494. Exterior View

Figure 495. Interior View

The plant is equipped with a 100-ton-capacity, indoor, bridge crane for assembly and maintenance of pumping units and associated equipment; a 50-ton-capacity, outdoor, traveling, gantry crane for assembly and maintenance of spherical discharge valves; and a 10-ton-capacity, outdoor, traveling, gantry crane for installation and removal of intake gates. The trashracks may be installed and removed by portable truck-mounted cranes.

Representative drawings are included at the end of this chapter.

Geology

Areal Geology

Wheeler Ridge anticline on the north flank of the San Emigdio Mountains is a complex structure of intensely folded and faulted, consolidated, sedimentary deposits of Tertiary Age. A combination of sedimentary rock, steep gradients, high-intensity runoff, and sparse vegetation has resulted in the erosion of deep gullies and the formation of large coalescing alluvial fans.

Site Geology

The plant was constructed on the alluvial fan abutting the northeast flank of Wheeler Ridge, an asymmetrical anticline plunging both east and west with a steep northeastern dip. Flanking Wheeler Ridge at the Wheeler Ridge thrust fault are the coalescing recent alluvial fans that overlay the Tertiary Tulare formation. Alluvial fans are nearly flat-lying deposits of sandy clay and silty sand with lenses of poorly graded sand and gravel. Tulare formation is a consolidated, interbedded, silty sand, silty-gravelly sand, silt, and clay, intensely folded and faulted.

The plant is adjacent to the surface-projected trace of the Wheeler Ridge thrust fault. Plant discharge lines cross the thrust fault and extend through a gap in the anticline, an erosional remnant of the past drainage pattern. Anchor blocks and pier supports are founded on both alluvial deposits and the Tulare formation.

Geologic Exploration

A 48-inch-diameter inspection hole was drilled to elevation 650 feet within the plant bowl. A man-cage was used to inspect the foundation and retrieve in-place side-wall samples. Design exploration included rotary drilling, auger drilling, and trenching.

Instrumentation

Slope indicators and rebound gauges were installed and monitored during construction. No significant movements were noted.

Seismicity

Wind Gap Pumping Plant is in an area of major seismic activity. The projected trace of the Wheeler Ridge thrust fault is immediately south of the plant and is crossed by the discharge lines. The projected trace of the White Wolf fault is north of the plant, and the Pleito fault extends through the San Emigdio Mountains south of the plant.

All faults in the area are considered active. The main shock of the 1952 White Wolf fault movement (7.7 Richter magnitude) originated in the vicinity of Wheeler Ridge. On May 27, 1964, the Consulting Board for Earthquake Analysis, responding to a question from the Department of Water Resources, stated "We consider it unlikely that there will be any significant fault displacements during the life of the structures."

Civil Features

Preliminary Studies

The plant location was controlled by the canal alignment upstream and a low saddle in the Wheeler Ridge Hills. The exact location of the plant was determined by economic studies of costs of the discharge line and head-loss costs versus cost of bowl excavation.

The design and specifications of Wind Gap Pumping Plant were prepared under contract by International Engineering Company, Inc. of San Francisco. This contract included design of the intake transition, plant structure, pumping equipment, appurtenances, and discharge lines. The Department established criteria and reviewed and approved all designs and specifications prior to construction.

Site Development

Initial bowl excavation for Wind Gap Pumping Plant was done separately from the plant construction contract. The floor of the bowl is approximately 110 feet below original ground at the plant site. Side slopes are 3:1 with a 20-foot berm at 40-foot vertical intervals. The bottom of the bowl excavation is roughly rectangular, approximately 530 feet long parallel to flow, and 640 feet wide.

Drainage from slopes is collected on berms and conveyed by pipe downdrains to a perimeter ditch at the bottom of the bowl. The perimeter ditch discharges through culverts into the forebay. Drainage from the cut for the discharge line is collected and drained into the forebay by means of two 48-inch, asbestos-bonded, asphalt-dipped, corrugated-metal pipes.

Plant Structure

The plant arrangement is basically the same as other pumping plants in the system, except the valve gallery is not enclosed within the superstructure. Valves are located under the downstream deck and are serviced through a hatch system using a 50-ton gantry crane. The valve deck was constructed using a waterproof membrane embedded in the concrete slab.

The plant is divided into five structural bays separated by expansion-contraction joints:

Bay No. 1—Plant service area
Bay No. 2—Three 315-cfs pumping units
Bays Nos. 3, 4, and 5—Two 630-cfs pump units each

The plant is founded on Recent alluvium that has been deposited over the Tulare formation at the Wheeler Ridge thrust fault. The unified soil classification is basically SM and SP and is generally nonplastic. Maximum design foundation loading was 5 tons per square foot.

Final foundation excavation for the Pumping Plant was protected with a 2-inch-thick coating of pneumatically applied concrete to control air slaking of the foundation surface.

Since the water table in the area is about 300 feet below plant foundation and the soil is sufficiently pervious to drain canal seepage, hydrostatic uplift pressures were not included in the plant stability analysis.

Shear keys are provided between all bays to help prevent differential movements between bays during earthquakes. A contraction joint is used below elevations 697.5 and 680.0 feet.

Exterior walls are designed to withstand "at rest" soil pressures and earthquake pressure using the Mononobe-Okabe formula. The equivalent hydrostatic pressure is computed to be 81 pounds per cubic foot.

Other design live loads are listed below.

Location	Live Load (psf)	Special Loading (Estimated)
Roof	25	
Erection Floor	1,000	Truck and trailer 70-ton
Motor Floor	1,000	
Transformer Deck	500	Transformer 125-ton and 50-ton valve gantry
Intake Bulkhead Deck	300	Gantry crane 10-ton capacity or H-20 truck
Mechanical, Electrical, and Pipe Gallery Floors	300	
Valve Floor	300	
Coupling Chamber Floor	300	
Visitors Balcony	150	
Stairs	100	
Plant Bridge Crane		Capacity 100-ton
Wind Load		In accordance with 1964 Uniform Building Code

Earthquake loads are carried through the floor slab diaphragms and end shear walls to the foundation.

On the south side of the plant, a special coupling chamber has been provided to protect the Pumping Plant if there is a break in the discharge lines. This chamber, isolated from the rest of the plant by watertight doors, is a continuous gallery with a riser shaft at the west end. A discharge culvert around the west side of the building empties into the forebay. A flap gate prevents wave action from spilling water into the culvert.

Waterways

Intake Facilities. The 287-foot-long intake transition widens from a canal bottom width of 24 feet to 295 feet at the face of the plant. The walls are on a 2:1 slope until they intersect vertical retaining walls extending from the plant.

The water table in the area is about 300 feet below plant foundation. Permeability measurements indicate the soil is sufficiently pervious to permit canal seepage to drain to the water table; therefore, the intake transition has an underdrain system to remove seepage water from behind the walls. The walls were not designed to resist the hydrostatic head caused by a rapid drawdown.

Each suction tube intake opening is equipped with a steel trashrack. Steel intake gates have been provided so each unit can be dewatered for servicing. Three gates have been furnished for the small units and four gates for the large units.

Pump Discharge Lines. The nine pumps at this plant lift water to a canal section on top of Wind Gap through four parallel, ring-girder-supported, steel, discharge lines. Three large lines have a diameter of 12 feet - 6 inches, and one smaller line has a diameter of 9 feet - 6 inches. All discharge lines are approximately 2,060 feet long from manifolds to outlet structure, and the first 200 feet downstream of the manifold junctions is buried. Discharge from pumping Units Nos. 1, 2, and 3 combines in the small line to flow at 945 cfs. The discharge from pairs of Units Nos. 4-5, 6-7, and 8-9 combines in the large pipes to flow at 1,260 cfs. Manifolds and main discharge lines were designed for a maximum dynamic head of 700 feet of water at the plant, 33% of which is due to hydraulic transients.

The main features of the pump discharge lines are the manifolds, main lines, and siphon outlet.

Manifolds. The manifold sections extend from the pump discharge valves to the end of the concrete encasements and include valve tapers, articulation sections, wye branches, and concrete-encased piping. Steel used in the manifolds is the same type used in the discharge lines. Steel-plate thickness for the pipe shell varies from $\frac{7}{8}$ to $1\frac{1}{2}$ inches, and manifold reinforcing rings range from 2 to 4 inches thick.

Articulation between each valve taper and manifold, as described in Chapter I of this volume, is provided by a short section of pipe supported between a pair of sleeve-type couplings.

Downstream of the articulation sections, the piping is manifolded. Manifolds, including the combined bends downstream of wye branches, are encased in reinforced concrete. Typical manifolds and encasement are described in Chapter I of this volume.

Main Discharge Lines. The main lines are welded steel pipes fabricated from heat-treated, manganese-silicon, steel plate of firebox quality. This steel is the same as that used in A. D. Edmonston Pumping Plant discharge lines and has properties similar to ASTM A537, Grade A steel.

Plate thickness on the small pipes varies from $\frac{3}{8}$ to $\frac{3}{4}$ inch and, on large pipes, it varies from $\frac{7}{16}$ to $1\frac{1}{8}$ inches.

The stiffener rings on the pipe shell are made of ASTM A36 steel. On the buried pipe, they resist earth loads and keep the pipe round. Stiffeners on the aboveground line modify the resonant frequency of the pipes to reduce vibration. Stiffener rings on aboveground pipes are spaced on 10-foot centers and are fabricated from plate. On the buried pipes, they are on 5-foot centers and consist of rolled structural tees. The 200 feet of pipe in each line downstream of the manifolds is bedded on consolidated pervious backfill which extends from an 18-inch depth below pipe invert up to a 120-degree bedding angle. Backfill from the consolidated material up to grade is compacted selected material.

In the remaining 1,800 feet of the discharge lines, the four pipes are supported on ring girders resting on concrete piers with an average spacing between piers of 40 feet. The pipe is on a relatively steep slope, which begins at 22% and increases to 40%. Large anchor blocks tie the pipes together at intervals of approximately 300 feet (Figure 496). Each pipe has an expansion joint located approximately 20 feet below each anchor to allow for temperature changes and other minor longitudinal movements.

Normal seismic loads were considered during design of the supports but this condition did not govern.

Siphon Outlet. The siphon outlet structure is a typical, steel-lined, reinforced-concrete structure, as described in Chapter I of this volume. This four-barrel structure has invert crests above the canal water surface elevation. Under normal and emergency dewatering conditions, backflow from the canal to each discharge line is prevented by the action of a siphon breaker valve which allows air (at atmospheric pressure) to enter the structure at each siphon crest.

Mechanical Features

General

The mechanical installation includes nine pumps and pump discharge valves, three equipment-handling cranes, and auxiliary equipment.

Chapter I of this volume contains information on mechanical equipment which is common to all plants. Information and descriptions which are unique to this plant are included in the following:

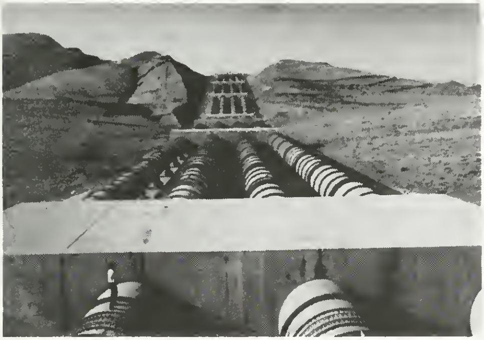

Figure 496. Discharge Line Anchor Blocks

Equipment Ratings

Pumps

Manufacturer: Allis-Chalmers Manufacturing Co.

Type: Vertical-shaft, single-stage, centrifugal

Pumps Nos. 1, 2, and 3

Discharge, each:	315 cfs
Total Head:	524 feet
Speed:	514 rpm
Guaranteed Efficiency:	91.5%
Minimum Submergence at Pump Centerline:	30 feet

Pumps Nos. 4 through 9

Discharge, each:	630 cfs
Total Head:	524 feet
Speed:	360 rpm
Guaranteed Efficiency:	92.0%
Minimum Submergence at Pump Centerline:	30 feet

Pump Discharge Valves

Manufacturer: Baldwin-Lima-Hamilton Corp.

Type: Units Nos. 1, 2, and 3—48-inch, double-seated, spherical

Units Nos. 4 through 9—66-inch, double-seated, spherical

Cranes

100-Ton Bridge Crane

Manufacturer: Crane Hoist Engineering and Manufacturing Co.

50-Ton and 10-Ton Outdoor Gantry Crane

Manufacturer: Broadline Corp.

Pumps

Pumps are vertical-shaft, single-stage, diffuser casing, centrifugal type, directly connected to synchronous motors. All pumps rotate counterclockwise as viewed from above (Figures 497 and 498).

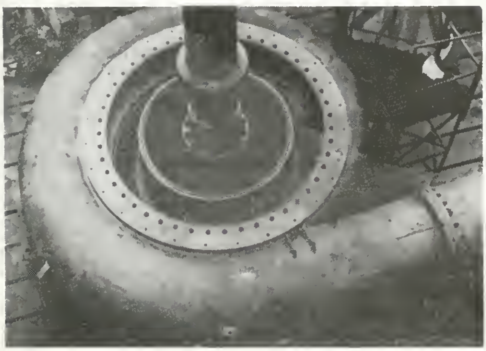

Figure 497. Partial Shop Assembly of Pump

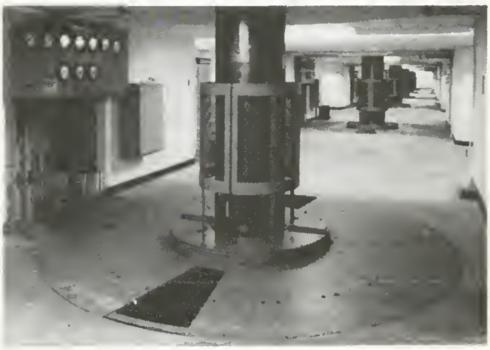

Figure 498. Pump Shaft Gallery

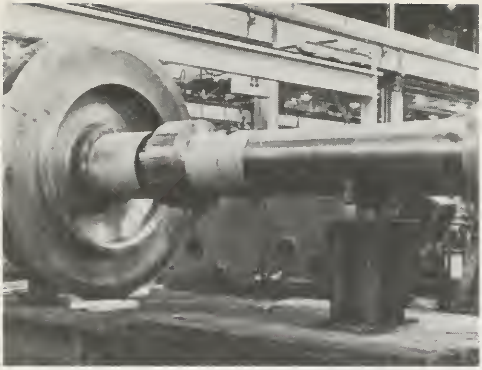

Figure 499. Pump Impeller and Shaft

Figure 500. Valve Body Casting

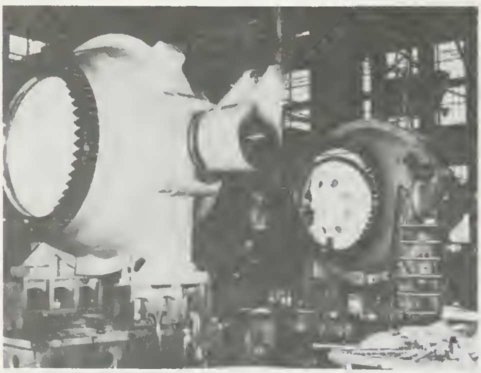

Figure 501. Shop-Assembled Spherical Valve

Casings are embedded in the concrete substructure of the plant. The pump impeller, shaft, guide bearing and housing, top casing cover, and wearing rings are all removable from above, after the motor rotor is removed. Hydraulic thrust and the weight of the rotating parts are carried by a thrust bearing in the motor.

The impellers are one-piece, enclosed, single-suction type, fabricated from annealed cast steel (Figure 499). The impellers have corrosion-resistant, steel (modified AISI-422), wearing rings. Areas on the impeller vanes that are susceptible to cavitation are overlain with stainless steel.

Removable and renewable wearing rings are located in suction and casing covers opposite the wearing rings on the impeller crown and band and made of AISI-422 stainless steel.

The pump guide bearing is the babbitted type with a self-lubricating oil system.

Pump Start-Up

Initially, the pump start-up procedure was designed to reduce the starting load on the motor by depressing water in the pump case below the impeller before closing the motor breaker and synchronizing. After synchronizing, air in the pump case was to be bled off through an air vent (located on top of the pump case extension) to allow the water to fill the case and prime the pump before opening the pump discharge valve for the pumping mode.

This method resulted in violent lifting of the rotating parts when water in the pump case reached the impeller. Also at shutoff head, before the discharge valve was opened, the rotating parts were floating off the motor thrust bearing. Many field tests were made to develop a solution to eliminate these unacceptable conditions. Before testing, a thrust collar was installed in the motor below the exciter to limit the amount of uplift and lessen the possibility of damage to the machinery.

A procedure was developed where water from the discharge line is introduced into the pump extension piece to fill the pump case before venting the air through the air release. This "backfilling" requires approximately one minute. Concurrently with backfilling, air from the pump case is vented to atmosphere from a point below the impeller eye. This method of filling the pump results in a condition where the impeller essentially is spinning in a bubble of air, which minimizes the momentum effect of the entering water. After backfilling for one minute, the air release valve is opened to allow the water to enter the pump and prime. After priming, the discharge valve is opened and pumping commences. This backfilling process is being incorporated into the automatic start-up procedures.

This procedure eliminated violent uplifting of the rotating parts. However, after priming and operating at shutoff head, the rotating parts were still floating, indicating that a higher pressure existed below the impeller than on top of the impeller. To lessen the pressure differential, a pipe connecting the top pump cover with the bottom cover outside of the wearing rings was installed. This modification eliminated floating of the rotating parts at shutoff head. Since the pump was embedded in concrete, it was necessary to core drill through several feet of concrete for the modification.

Pump Discharge Valves

A double-seated spherical valve was installed on the discharge side of each pump. The valves are used as shutoffs to prevent backflow through the units when they are stopped and to isolate each pump from its discharge line for inspection and maintenance (Figures 500 and 501).

Units Nos. 1, 2, and 3 have 48-inch-diameter valves, each weighing approximately 50,100 pounds, and Units Nos. 4 through 9 have 66-inch-diameter valves, each weighing approximately 77,000 pounds.

The operating mechanism for each valve is basically composed of an operating cylinder with a piston and piston rod, operating lever, and locking device. The cylinder is double-acting, with the control system set up to simultaneously vent one side of the cylinder to the oil sump tank and allow oil to enter the other side under high pressure from the accumulator tank. Rate of valve movement is controlled by a metering valve on the discharge side of the cylinder.

Each valve plug is rotated by its individual hydraulic system, pressurized by an air-over-oil accumulator. Each system, operating at a nominal pressure of 500 pounds per square inch (psi), is capable of one opening cycle and two closing cycles, after which the system pressure drops to 375 psi.

Equipment in each system includes an oil accumulator; oil sump tank and pumps; air compressor; directional and flow control valves; hydraulic control panel; valve control center; and necessary piping, wiring, and instruments (Figure 502). The air compressor and two hydraulic oil pumps supply air and hydraulic fluid, respectively, to the accumulator. The compressor and pumps normally are operated automatically but can be operated manually from the valve control center.

Valve seats are oil-operated and are located upstream and downstream of the transverse valve centerline. Seals are so arranged that either the upstream or downstream ring can be moved independently. The upstream seat is used as an operating seat, and the downstream seat is maintained in the open position and used as a shutoff valve when maintenance is required on the operating seat or on the pumps.

The pump discharge valve is operated only in the fully open position during normal pumping. Opening and closing of the valve is controlled by a mechanical-electrical sequencer using cam-operated switches and hydraulic valves. Cams are mounted on a shaft which is driven by a 125-volt direct-current motor. The motor is controlled by a reversing starter whose forward and reverse contactors are energized and deenergized by plug and seat-limit switches and the cam-actuated switches mentioned above.

Valves will open or close at an approximately uniform rate, with the closing times being equal for normal or emergency conditions.

Equipment Handling—Cranes

Assembly and maintenance of major pumping plant equipment, including pumps and motors, is by a 100-ton, indoor, bridge crane (Figure 503). A 50-ton, outdoor, gantry crane handles the discharge valves. The plant also has a 10-ton, outdoor, gantry crane which raises, lowers, and transports the intake bulkhead gates.

The bridge crane is an electric, cab-operated, overhead traveling type, with a main 100-ton-capacity hook, and an auxiliary 25-ton-capacity hook. A sister hook, bored for a lifting pin, is provided for the main hoist.

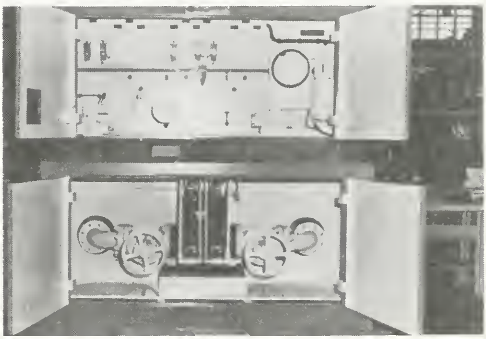

Figure 502. Valve Hydraulic Control Cabinet

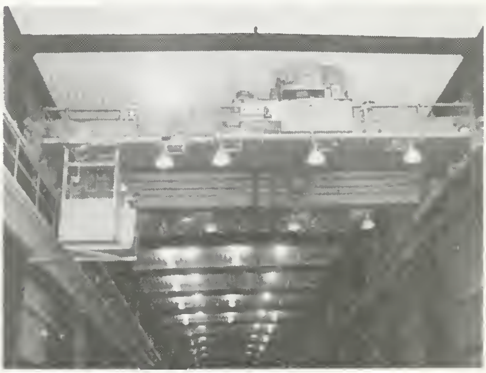

Figure 503. 100-Ton Bridge Crane

Rated capacities and speeds of the bridge crane are:

Rated capacity, tons	100
Number of trolleys	1
Rated capacity of main hoist, tons	100
Rated capacity of auxiliary hoist, tons	25
Maximum lift, main hoist, feet—inches	72′—2″
Maximum lift, auxiliary hoist, feet—inches	84′—2″
Span, feet—inches	43′—7½″
Hook, Speeds—feet per minute (fpm)	
Main (5 step)	3.0
Aux. (5 step)	15.0
Bridge speed—fpm	80–90
Trolley speed—fpm	30–35

Brakes are provided for hook, trolley, and crane travel. They include both electric and hydraulic shoe type, with shunt coil and manual release lever.

The 50-ton, outdoor, gantry crane operates on steel rails embedded in the plant valve access deck. The lifting mechanism consists of a sister hook suspended from a four-sheave snatch block.

Rated capacity and speeds of the 50-ton gantry crane are:

Rated capacity, tons	50
Number of trolleys	1
Span, feet—inches	12′—0″
Hoist speed with maximum working load, fpm (two speeds)	3.72 1.24
Gantry travel speed with maximum working load, fpm	30 to 40
Maximum lift, feet—inches	53′—0″

The 10-ton, outdoor, gantry crane operates on steel rails in the plant gate deck. The lifting mechanism consists of a lifting beam suspended from twin snatch blocks.

Rated capacity and speeds of the 10-ton gantry crane are:

Rated capacity, tons	10
Number of trolleys	1
Span, feet—inches	15′—0″
Hoist speed with maximum working load, fpm (two speeds)	4 to 5 8 to 10
Gantry travel speed with maximum working load, fpm	30 to 40
Trolley travel speed with maximum working load, fpm	3 to 5
Maximum lift, feet—inches	39′—0″

Hydraulic Transients

Surge and reverse speed controls are provided by a single-speed discharge valve closure.

The calculated upsurge, downsurge, and reverse-speed conditions with the one-speed closure of 22 seconds were well within the design limits. Field tests have verified the calculated results.

Auxiliary Service Systems

The auxiliary service systems at the plant are detailed in Chapter I of this volume. Items unique to this plant are noted below.

Motor Cooling Water System. The cooling water system is used to provide the required cooling water for the main motor air coolers, main motor bearing oil cooling coils, and unit pump guide bearing oil cooling coils.

Nine main units in the Pumping Plant are served by four independent cooling water pump systems as shown in the following table:

Pump Units	Normal Operation	Standby
Units Nos. 1, 2, and 3 Served by	P-1, P-2, & P-4	P-3
Units Nos. 4 and 5 Served by	P-5 & P-7	P-6
Units Nos. 6 and 7 Served by	P-8 & P-10	P-9
Units Nos. 8 and 9 Served by	P-11 & P-13	P-12

Each cooling water pump has an individual inlet strainer located in the plant forebay area. The cooling water passes through an automatic self-cleaning strainer and then discharges into a common system header. Operation of the automatic strainers is tied into the operation of the cooling water pumps.

Cooling water systems for Units Nos. 1, 2, and 3 are supplied from a common header, and the supply valve to the respective unit cooling water system is automatically opened when the cooling water pump is started and closed when the unit is shut down. Cooling water pump discharge headers of main pump Units Nos. 4-5, 6-7, and 8-9 are equipped with manually operated sectionalizing valves, arranged so that one cooling water pump serves one main pump unit. The above arrangement provides the necessary flexibility of transferring to a second pump when the normally operating cooling water pump is inoperative.

After cooling water passes through the coils and through the branch lines, it is then joined into a common header and discharged back to the forebay.

Raw Water System. The raw water system consists of three raw water pumps located in the mechanical gallery; one booster pump (discharge line fill) located in the valve gallery; and related piping, controls, and appurtenances. This system provides water for the main pump wearing rings, air-conditioning condenser coils, and filling the discharge line.

Two of the raw water pumps, which are alternator-controlled, run simultaneously or separately depending upon system demand. The third pump is a manually controlled standby unit. The pumps are controlled by two pressure switches located on the raw water header and a flow switch in the raw water discharge line to the booster pump header. Each raw water pump has an individual, automatic, self-cleaning strainer whose operation is tied into the pump operation.

The booster pump takes its suction from the raw water pump discharge header and is used to fill the discharge line, operating in series with the two raw water pumps. A bypass around the booster pump is provided for use when it is not desired to operate the booster pumps.

Oil System. The oil used in the plant for lubrication of the pump and motor bearings and for the hydraulic fluid in the pump discharge valve hydraulic system is a high-grade turbine type having a viscosity of 280 to 330 SSU at 100 degrees Fahrenheit.

Electrical Features

General

The electrical installation includes a 230-kV switchyard; power transformers; motors; switchgear; and auxiliary systems for station service, communication, and protection of equipment and personnel.

Chapter I of this volume contains information on the electrical equipment and systems for Wind Gap Pumping Plant common to other State Water Project plants.

Description of Equipment and Systems

Motors are operated from a 13.2-kV system. The three smaller motors are started full-voltage and with the pump case dewatered. The six larger motors are started with a system which reduces voltage and with the pump case dewatered. Distribution transformers are connected with the high-voltage winding in series with the grounded neutral of the wye-connected motors and with resistors connected in the low-voltage windings. This limits the magnitude of ground fault currents and detects abnormal currents for breaker tripping. Surge protection from transient overvoltages is provided by capacitors and lightning arresters on the line side of each motor.

Three 3-winding transformers and one 2-winding transformer are installed to reduce voltage to 13.2 kV for operating the motors and for station service supply. The transformers connect to an open bus structure at the plant. The bus-yard is connected to the switchyard by two overhead load lines.

Metal-clad circuit breakers connect the motors and station service transformers to nonsegregated-phase bus on the low-voltage side of the transformers (Figure 504). Circuit breakers are used for both normal operation and tripping on abnormal conditions.

Two station service transformers supply a double-ended substation and reduce the supply to 480 volts (Figure 505). Power to the motor control centers, power distribution centers, and lighting distribution centers located throughout the plant is distributed by 480-volt feeder breakers in the substation (Figure 506).

Figure 504. Motor Control Equipment—Field Excitation, Protective Relays, and 15-kV Switchgear

Figure 505. 480-Volt Station Service Substation

Figure 506. Cable Tray Gallery

Switchboards house the protective relaying, instruments, meters, annunciators, and local operating panel. These boards are provided for each pumping unit (Figure 507).

Pumping units and auxiliaries are controlled from the control room (Figure 508). A computer control system was installed in the plant operating control room with complete facilities for controlling, monitoring, logging data, annunciating, and displaying all requirements and functions of the plant and switchyard. In addition to operating the plant from the control room, equipment was installed for operating each unit in a local mode at its switchboard. A panel is provided on each switchboard to selectively start each pumping unit. Volume V of this bulletin gives a more detailed description of the control systems, both in the plant and remote from the plant.

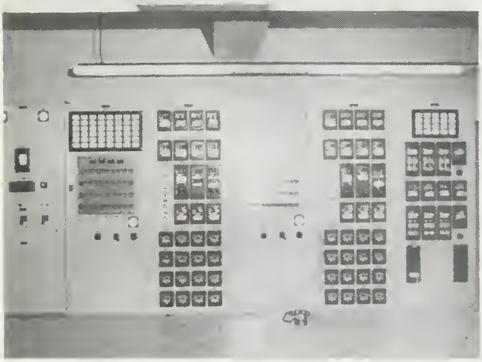

Figure 507. Control Switchboard

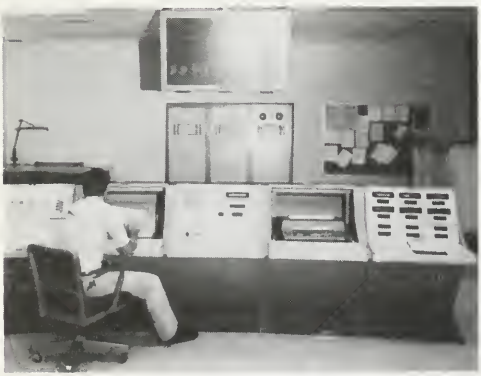

Figure 508. Control Room

Equipment Ratings

Motors

Manufacturer: Westinghouse Electric Corporation
Type: Vertical-shaft, synchronous
Power factor: 95%
Frequency: 60 Hz
Phase: 3
Volts: 13,200

Motors Nos. 1, 2, and 3

Horsepower: 22,000
Speed: 514 rpm

Motors Nos. 4 through 9

Horsepower: 44,000
Speed: 360 rpm

Power Transformers

Manufacturer: General Electric Company
Volts: 220-13.2 kV
Taps: In the high-voltage winding, 2½ and 5% above and below rated voltage
Phase: 3
Frequency: 60 Hz
Type: OA/FA
Connection: Grounded Wye-Delta

Transformer No. 1

kVA: 40,500/54,000
Windings: One high-voltage and one low-voltage

Transformers Nos. 2, 3, and 4

kVA: 53,300/71,000
Windings: One high-voltage and two low-voltage

Station Service

Number of transformers: 2
Volts: 13,800—480Y/277
Phase: 3
Frequency: 60 Hz
kVA: 1,000/1,333
Type: AA/FA
Emergency engine-generator: 75 kW, 480Y/277 volts, 3 phase, 60 Hz

Motor Starting Method

The plant pumping units are started daily for off-peak pumping, which imposes a difficult starting duty on the motors and load on the utility company. Different methods of starting were evaluated.

The three smaller motors were within acceptable criteria for starting full-voltage, that is, the 22,000 horsepower (hp) and speed reduced the inrush to acceptable limits of the utility and were not considered to cause an excessive starting duty for the motors. A study also considered the economic aspects of the choices of the starting method. Full-voltage starting required a minimum of auxiliary equipment; costs would be less for the equipment and starting reliability greater. Water was depressed from the pump case to reduce the starting torque requirements. Motor costs were estimated to be over 25% greater with a watered start.

Two other methods of starting were considered for the 44,000-hp motors since full-voltage starting would exceed the limits set by the utility for inrush kVA (Figure 509). One method was to use a reactor in the motor neutral during starting and switch the reactance from the circuit after the motor had synchronized. The second and selected method consists of using three-winding transformers with two electrically separate secondary windings. One motor is connected to each 13.2-kV winding. Due to the impedance characteristic of the three-winding transformer, starting is actually accomplished at reduced voltage. With a motor started across one of the windings, the winding impedance increases to a higher value than when the motor is operating normally. The result of this transformer characteristic is that the motor is essentially started with a high-impedance transformer. As the motor accelerates, inrush is reduced and transformer voltage returns to its normal value.

Station Service System

For reliable station service, two independent power supplies were selected. One supply is taken from a two-winding transformer and the other from a three-winding transformer. The circuits originate at opposite sides of the switchyard. The three-winding transformer connection required circuitry for selecting the low-voltage winding to be utilized because the station service connection could not be made to the same winding being used to start a motor. Otherwise, the high-voltage drop experienced during motor starting would adversely affect the station service system.

230-kV Interconnections

The switchyard is supplied by two transmission lines which also supply power to Wheeler Ridge and Buena Vista Pumping Plants and a load external to the Department's facilities. Normally, the bypass switch in the yard is open, and each circuit supplies power to half of each of the three pumping plants. During maintenance of switchyard equipment, the bypass switch is closed and half of the yard is taken out of service. The entire pumping plant is then supplied by the remaining transmission line connection.

The selected arrangement is considered to have sufficient flexibility for normally expected situations. Full protection is provided; costs were kept to a minimum by reducing the number of breakers and bays to two.

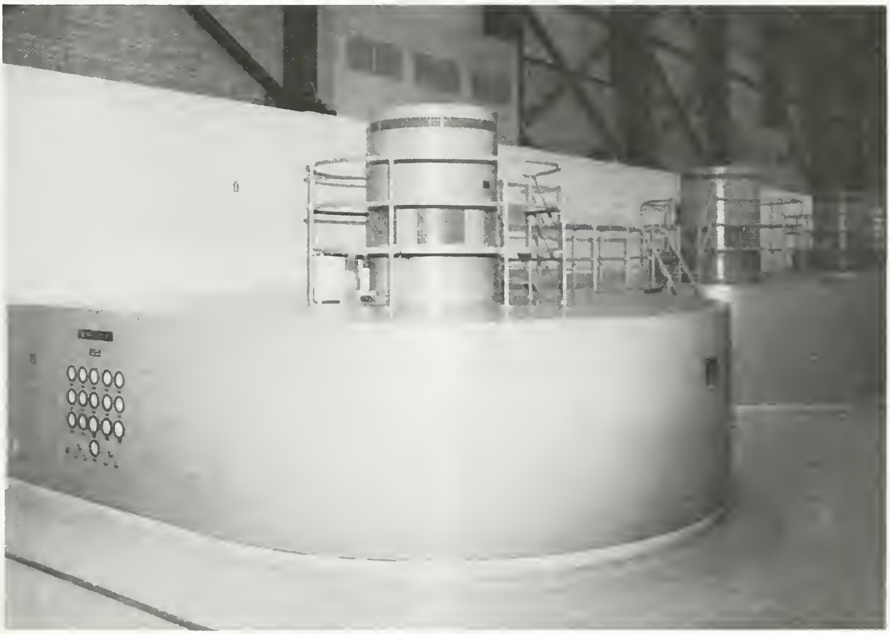

Figure 509. 44,000-Horsepower Synchronous Motor

Figure 510. View of Plant and Discharge Lines

Construction

Contract Administration

Numerous construction contracts were issued to build this plant (Figure 510). General information about the major contracts for construction of this plant is shown in Table 11.

Preconsolidation

Preconsolidation of subsurface soils by hydrocompaction was performed in areas where facilities were constructed in cuts less than 100 feet deep. Work performed under preconsolidation contracts is described in detail in Volume II of this bulletin.

Bowl and Intake Channel Excavation

Excavation for the Wind Gap and Wheeler Ridge Pumping Plant bowl and intake channels was performed under the same contract. The excavation at Wind Gap was performed from April to September 1966 and in March and April 1967. A total of 6,707,000 cubic yards was excavated. Except for 400,000 tons sold to aggregate suppliers, for which the Department received a royalty, excavation was wasted in spoil areas adjacent to the intake channel. The excavation equipment employed included twin-engine 40-cubic-yard scrapers and large dozers.

TABLE 11. **Major Contracts—Wind Gap Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Intake channels, Wheeler Ridge, and Wind Gap Pumping Plants	66-11	$4,575,273	$4,842,573	$10,505	4/ 5/66	8/31/67	Gordon H. Ball Enterprises & Altfillisch-Fulton Co.
Pumps	67-31	2,293,000	2,705,000 (Est.)	3,807*	8/17/67	12/74 (Est.)	Allis-Chalmers Mfg. Co.
Pump discharge valves	67-49	2,022,121	2,260,740	9,564	10/30/67	4/19/73	Baldwin-Lima-Hamilton
Bridge cranes (including Buena Vista, Wheeler Ridge, and Oso Pumping Plants)	67-57	423,850	453,676	10,622	12/13/67	10/13/69	Crane Hoist Engineering & Mfg. Co.
Pumping plant construction	67-59	11,825,083	13,096,369	206,384	12/19/67	8/ 4/70	J. H. Pomeroy & Co., Inc.
Power circuit breakers (including Buena Vista and Wheeler Ridge Pumping Plants)	67-70	409,840	437,204	2,701	12/29/67	6/24/71	Westinghouse Electric Corp.
Motors	68-03	3,691,953	4,498,712	95,399	5/21/68	4/17/73	Westinghouse Electric Corp.
Power transformers	68-06	851,244	908,571	--	3/ 7/68	11/ 1/72	General Electric Co.
13.8-kV switchgear, duplex switchboards, and associated equipment	68-19	775,040	853,167	38,403	10/18/68	4/13/71	Federal Pacific Electric Co.
Station service substation and distribution centers	68-36	158,908	162,669	—1,430	10/31/68	11/ 1/71	I.T.E. Circuit Breaker Co.
Completion contract (including Wheeler Ridge Pumping Plant)	68-49	6,345,852	7,740,917	1,006,173	4/ 1/69	2/ 6/73	Wismer & Becker Contracting Engineers

* As of November 1974

Dewatering Operations

The drainage systems for the bowls and intake channels for the two plants consisted of training dikes, drainage channels, air-blown-mortar-lined ditches, corrugated-metal pipe culverts, and asbestos-cement pipe slope drains. The training dikes and drainage channels were constructed in conjunction with the earthwork operations and the culverts in conjunction with access roads. Surface runoff and cure water were collected in the main sump of the plant's service bay and pumped out of the bowl. The ground water level wasn't reached during excavation so no dewatering was performed prior to the construction of the sump.

Structural Excavation and Backfill

Equipment used for Wind Gap Pumping Plant foundation excavation included a motor grader, a tractor, and three tandem scrapers. Excavation for the pumping plant structure began in January 1968. Approximately 15,600 cubic yards of excavated material was deposited across the canal cut upstream of the plant site to form a crossing for equipment and a site for the concrete batch plant. The remainder of the excavated material was stockpiled along the west side of the bowl for later use as structural backfill. Excavation for the discharge line anchor blocks was performed between January and March 1968 using a tractor with a dozer blade.

A vibratory roller was used to compact the pumping plant foundation. On the foundation slopes, the roller was raised and lowered with a truck-mounted crane. The required 95% relative compaction was obtained.

Compaction of backfill around the pumping plant structure was accomplished with air hammers and whackers until space permitted use of a tractor-drawn sheepsfoot roller. Relative compaction of 95% was obtained. After installation of the 48-inch-inside-diameter corrugated-metal pipe, a free-draining backfill was placed up to the culvert springline. Three-inch immersion-type vibrators were used to consolidate this cohesionless material, above which was placed normal backfill material.

Consolidated backfill was also used around buried portions of the discharge lines. The required 70% relative density was obtained by saturating the material with water before vibrating it into place.

Pneumatically Applied Mortar

A layer of mortar (shotcrete) was applied on all load bearing surfaces of foundation excavation. It was applied immediately after completing the excavation to protect the surfaces from air slaking until they were covered by structure and backfill concrete.

Shotcrete was also applied beneath discharge lines and in the drainage ditch around the bowl perimeter. The shotcrete applied to the plant foundation was 2 inches thick; the discharge line application was 3 inches thick.

Shotcrete application for the plant was performed so that it could be covered by structure concrete within the 90-day maximum specified period. To facilitate shotcrete pumping problems, ¾-inch maximum size aggregate was reduced to ½ inch.

Concrete Placement

Concrete was batched at a portable plant erected at the site. The batch plant holding hoppers were designed to allow two 4-cubic-yard batches to be held simultaneously. Two different mixes were accommodated when placements for the plant and discharge lines were coincident (Figure 511).

Structure concrete for the Pumping Plant was transported to the placement area in concrete buckets handled by tower cranes. Concrete was transported by 8-cubic-yard-capacity haul trucks for pumping plant areas out of reach of the tower cranes. At these placements, a truck-mounted crane with a 2-cubic-yard bucket handled the concrete. A combination of 3-inch and 6-inch vibrators was used to consolidate the concrete. Three-inch maximum size aggregate was used for structure concrete wherever space allowed.

Discharge Lines

On-site fabrication was required for the 12-foot - 6-inch-diameter straight section and for the manifold sections. Each straight section was shipped to the site in a 30-foot- and a 10-foot-long piece. The two pieces were welded together as they slowly turned together on rollers. After welding, each section was sandblasted, externally coated with inorganic zinc silicate, and internally coated with coal-tar epoxy.

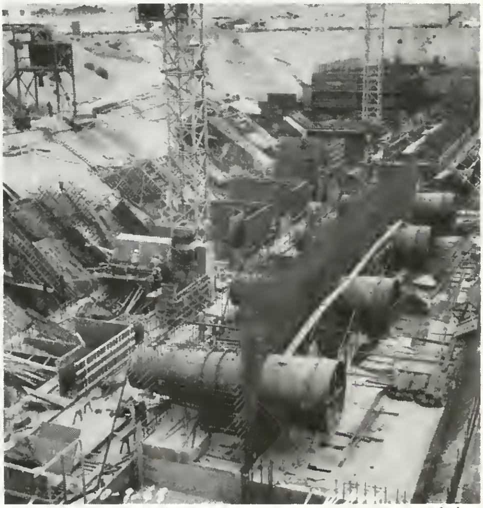

Figure 511. Concrete Placement of Taper Sections Near Bottom of Plant

The pipe sections were put on a sled and placed at the top of skidways extending down the discharge line slope (Figure 512). Two lines were installed simultaneously using two skidways. A 40-ton-capacity dual-drum winch lowered the sections down the skidways into position (Figure 513).

All elbow and manifold joints were hand-welded. Where radiographing the joints was impractical, ultrasonic testing was used.

Other Construction

Second-stage concrete and embedment of pump scroll cases in concrete were accomplished under the contract for the completion of Wheeler Ridge and Wind Gap Pumping Plants, Specification No. 68-49, as well as the installation of most of the piping, wiring, drainage pumps, compressors, water and sewage treatment plants, air conditioning, interior finishing, and yard paving.

Pumps, motors, and other major mechanical and electrical equipment were furnished and installed under separate contracts.

The computer control system, an important part of this plant, is described in Volume V of this bulletin.

Figure 512. Skidding First Discharge Line Pipe Section for Pumping Plant Line No. 1 Downslope

Figure 513. First of Three 150-Inch-Inside-Diameter Steel Discharge Lines for Plant Being Installed on the Support Piers

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 514 through 545).

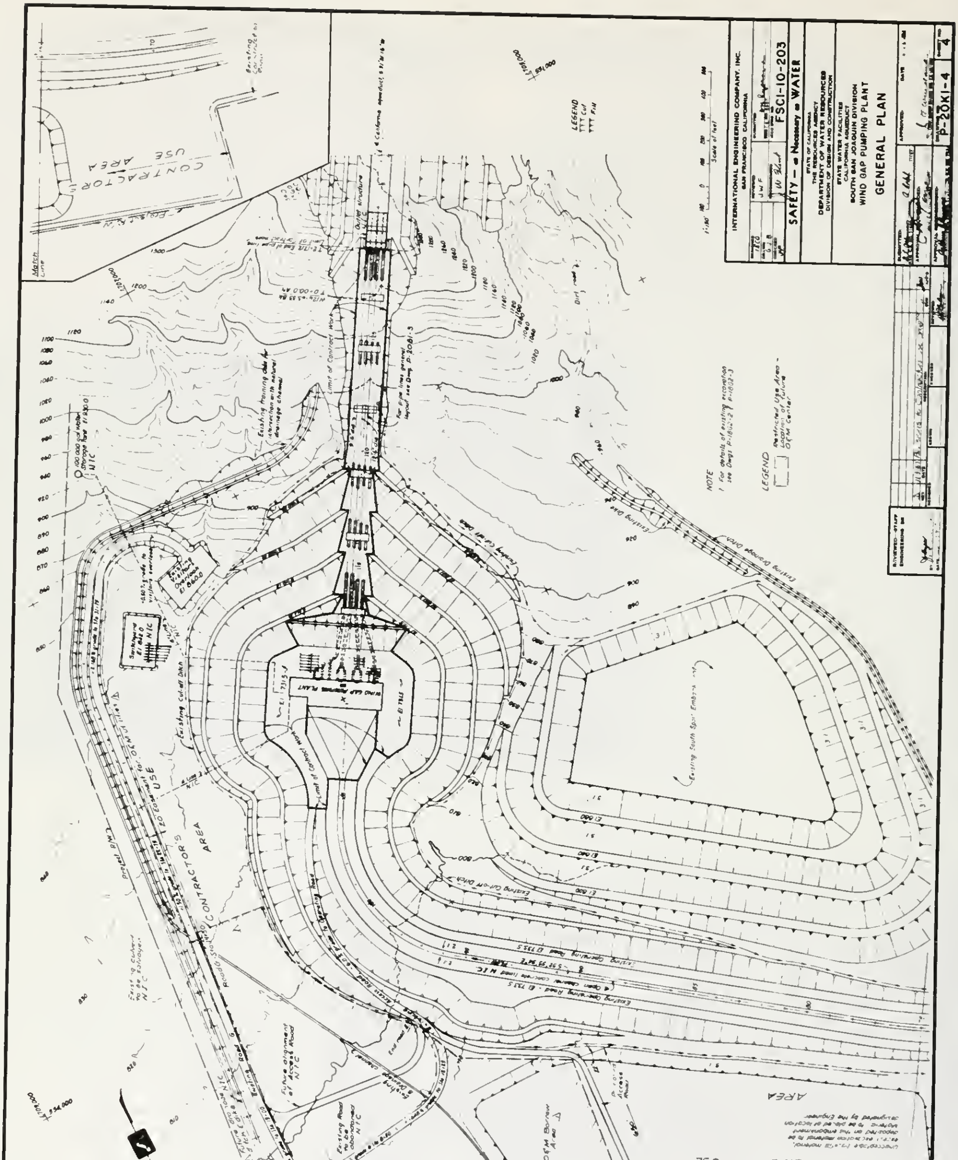

Figure 514. General Plan

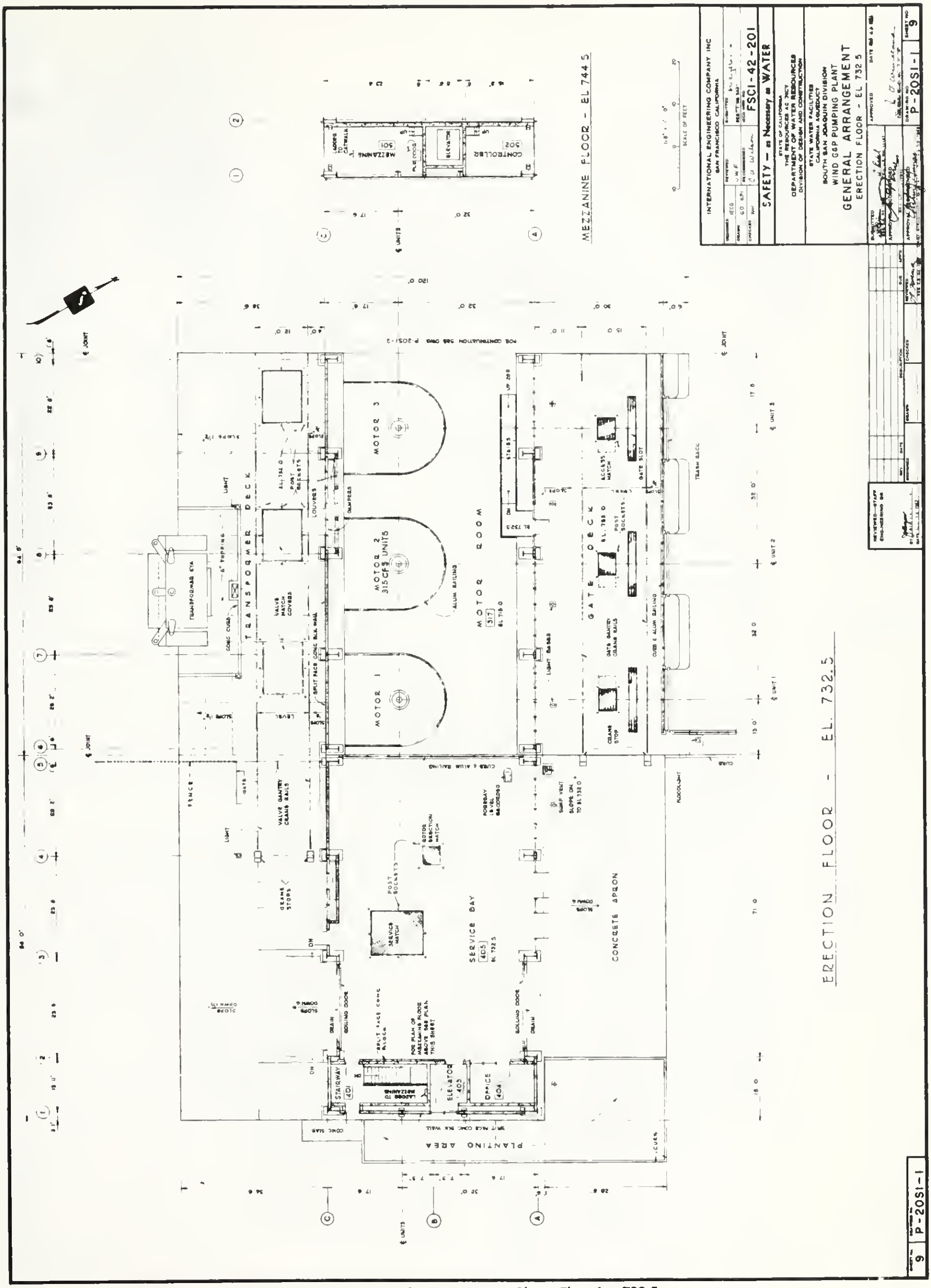

Figure 515. General Arrangement—Plan—Elevation 732.5

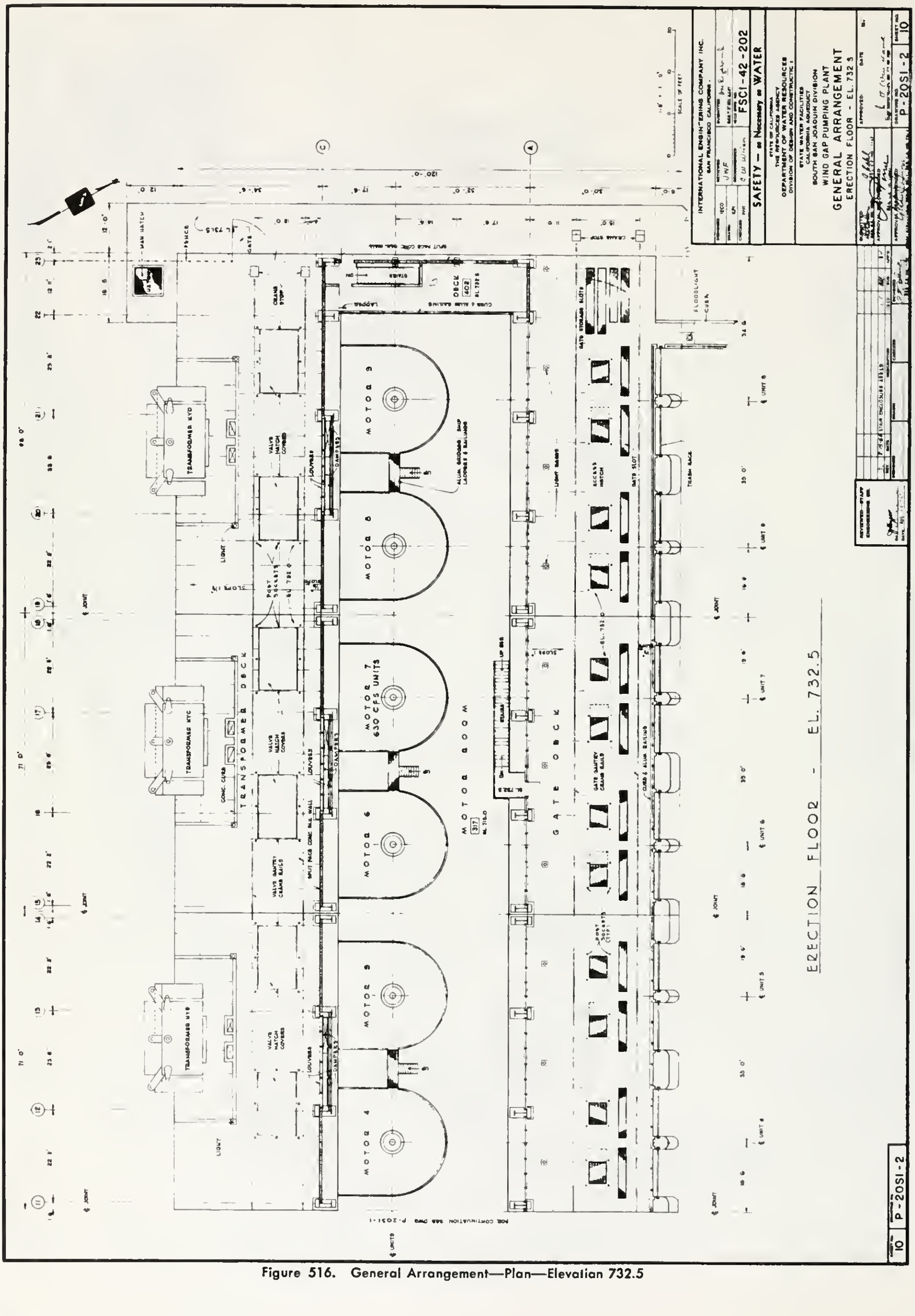

Figure 516. General Arrangement—Plan—Elevation 732.5

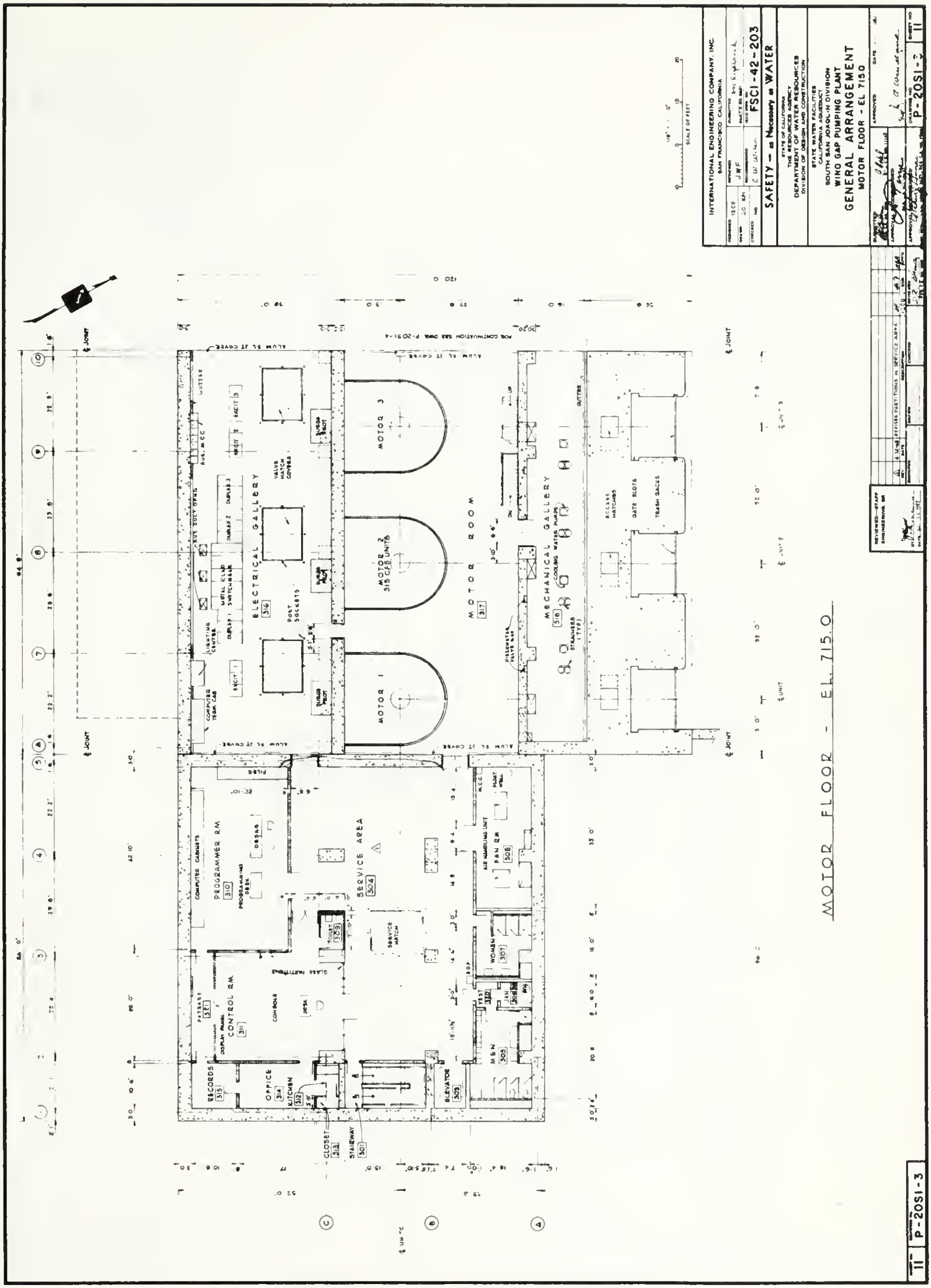

Figure 517. General Arrangement—Plan—Elevation 715.0

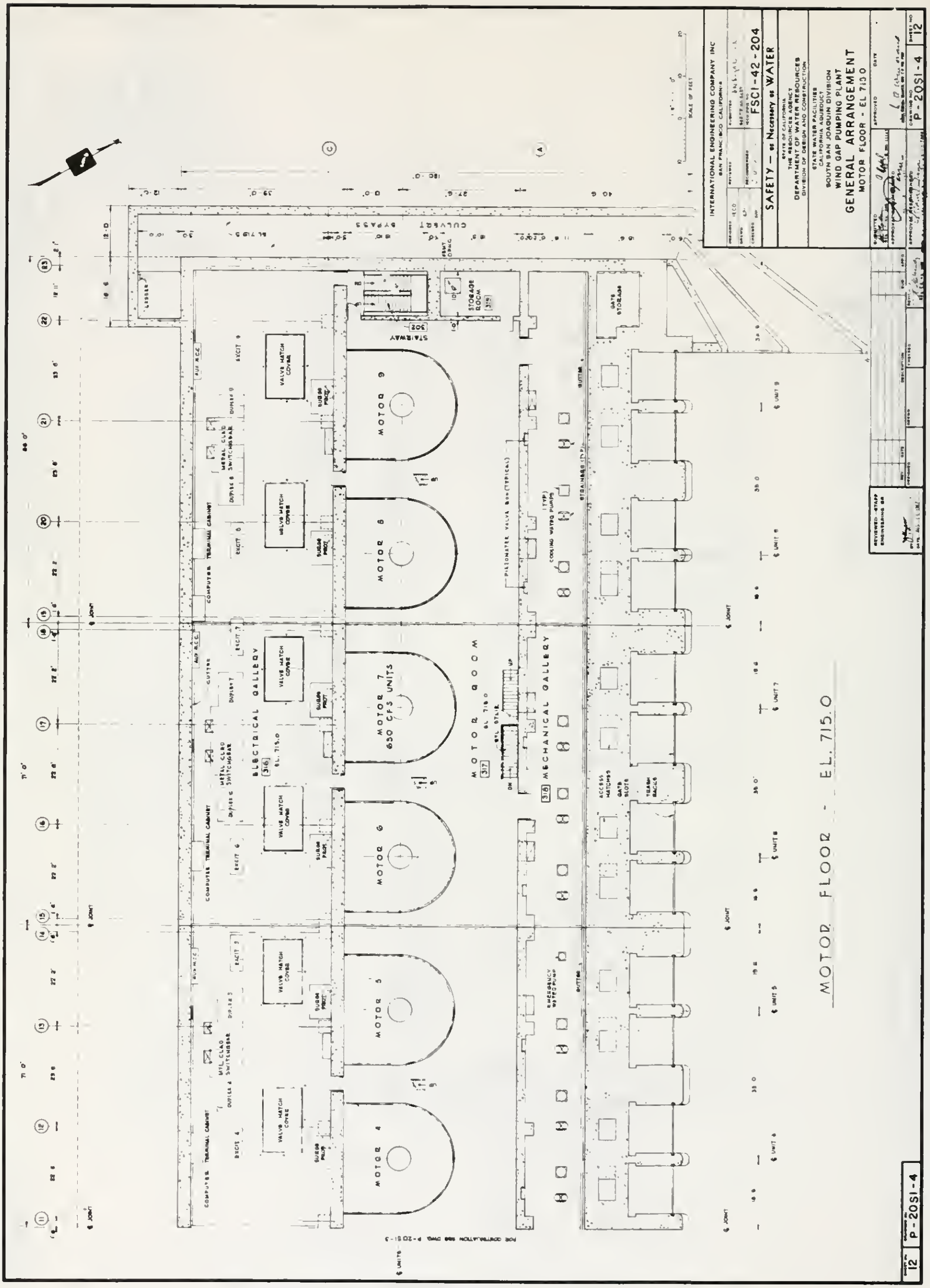

Figure 518. General Arrangement—Plan—Elevation 715.0

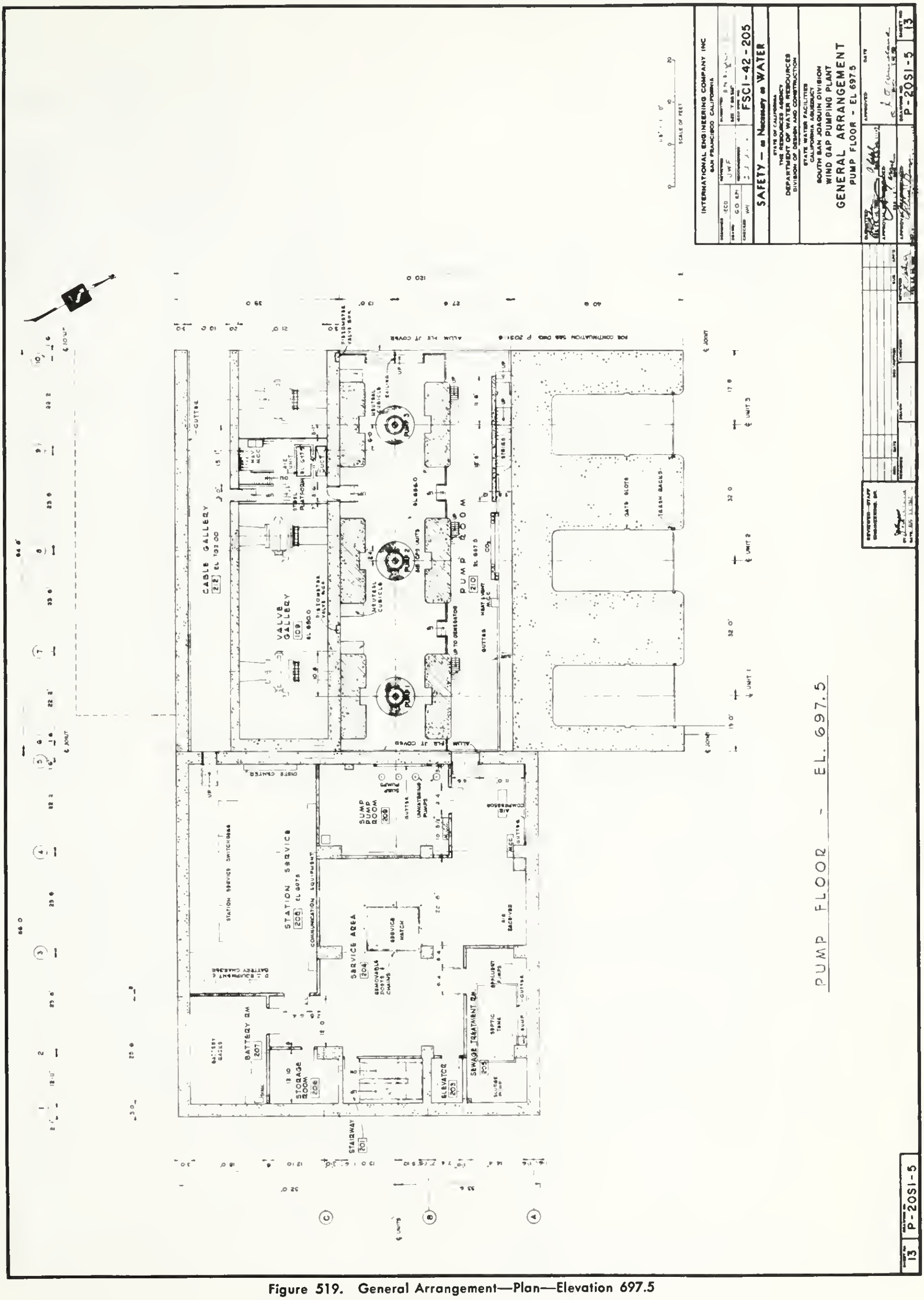

Figure 519. General Arrangement—Plan—Elevation 697.5

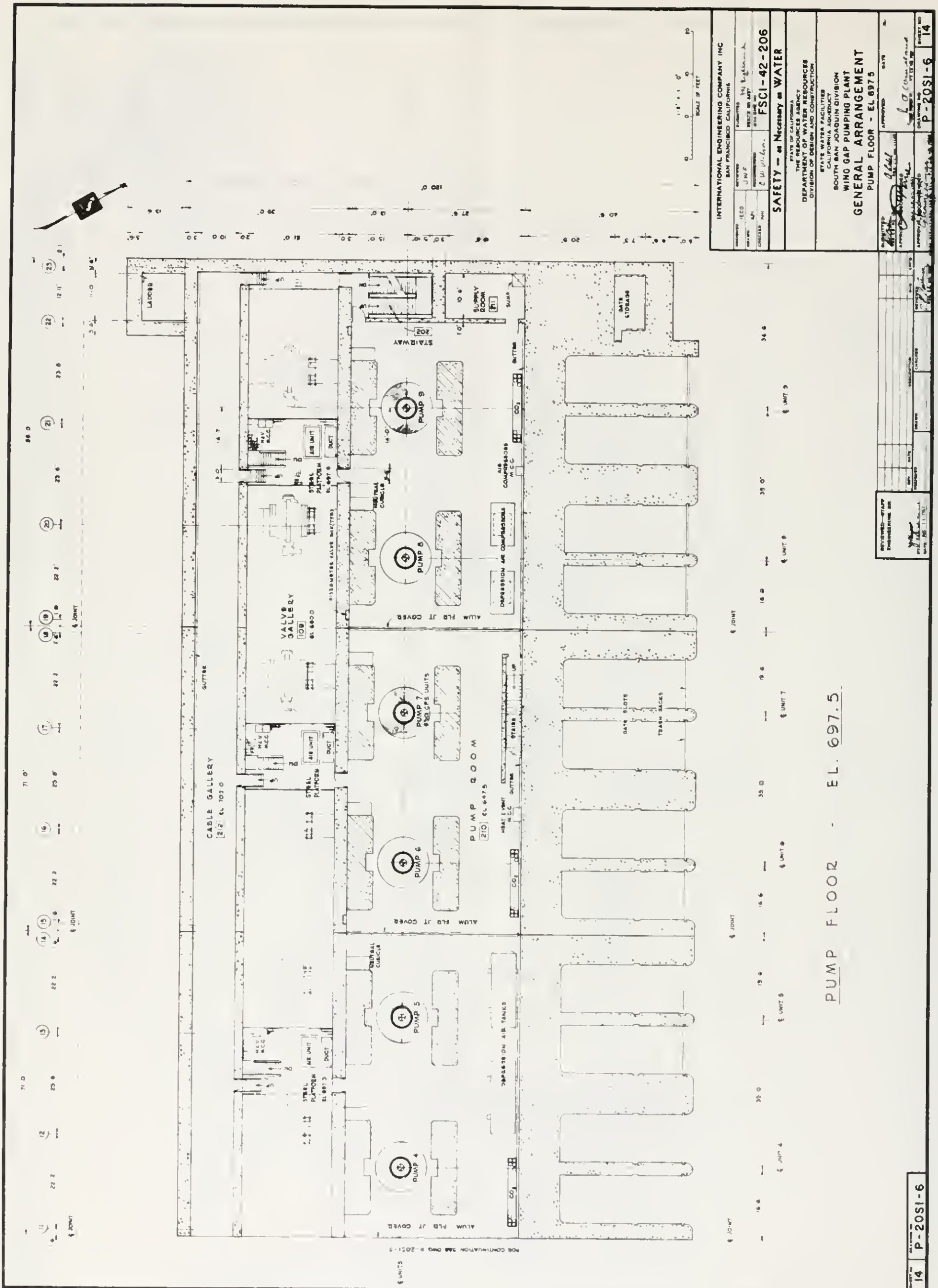

Figure 520. General Arrangement—Plan—Elevation 697.5

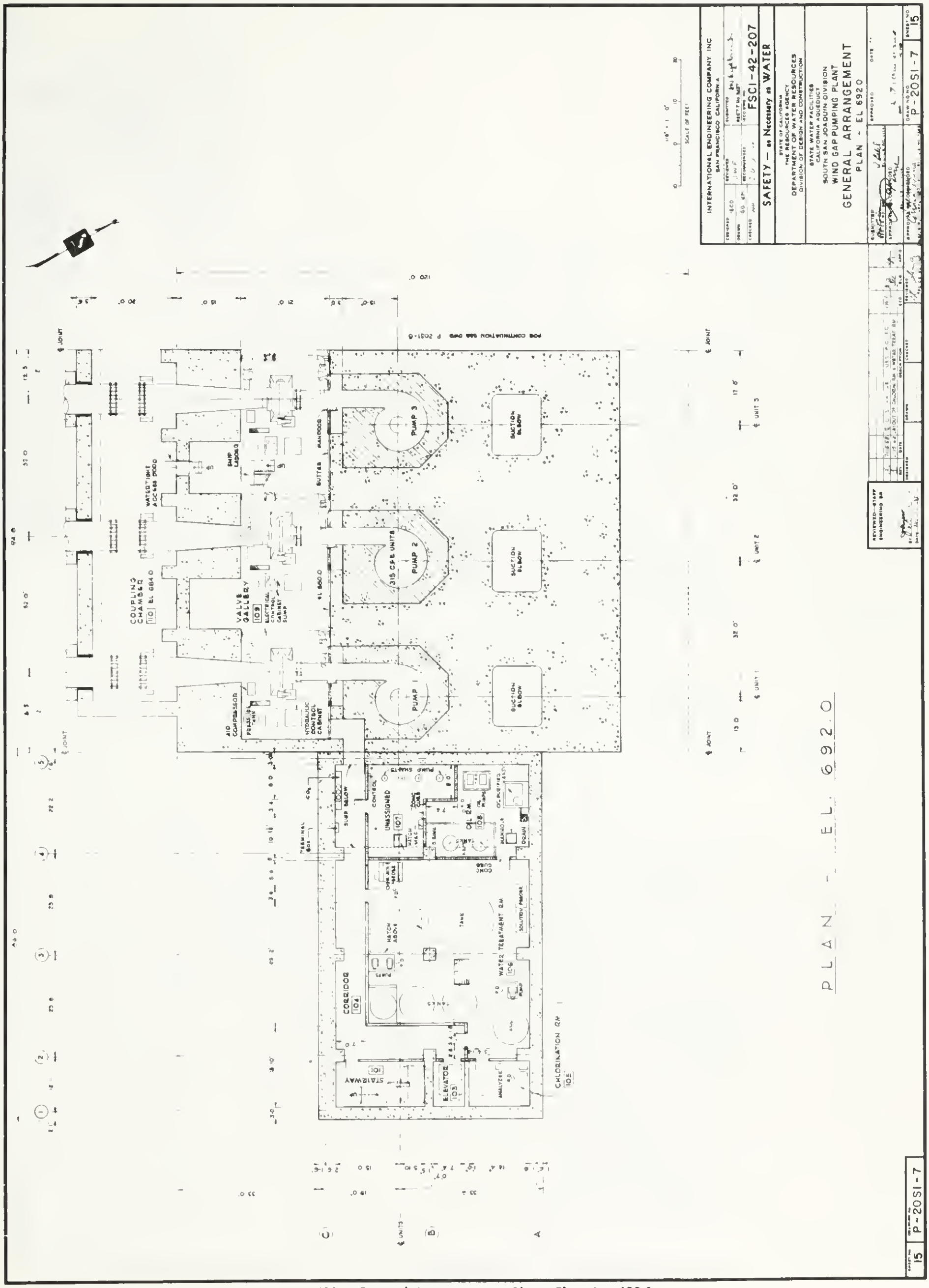

Figure 521. General Arrangement—Plan—Elevation 692.0

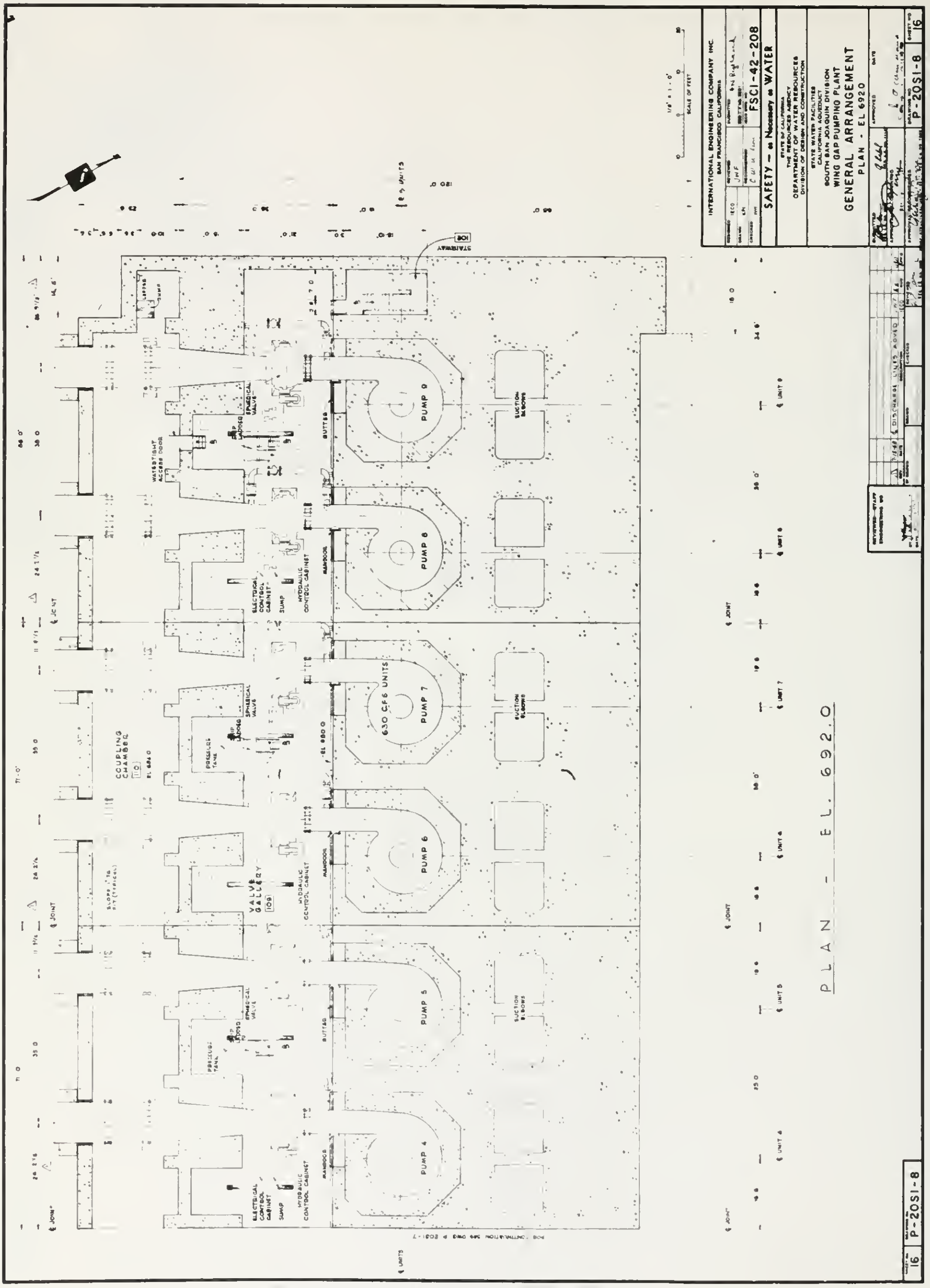

Figure 522. General Arrangement—Plan—Elevation 692.0

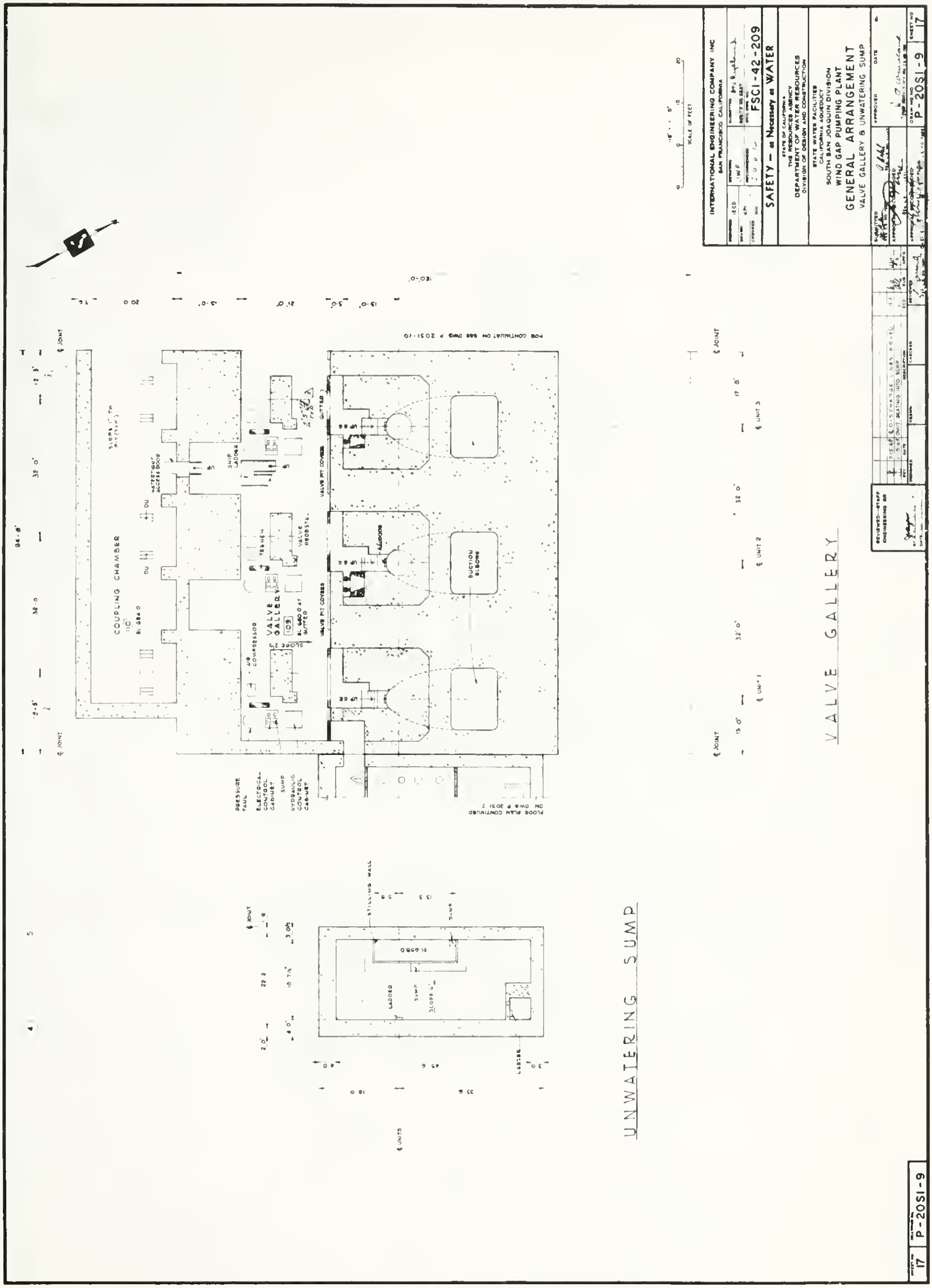

Figure 523. General Arrangement—Valve Gallery and Dewatering Sump

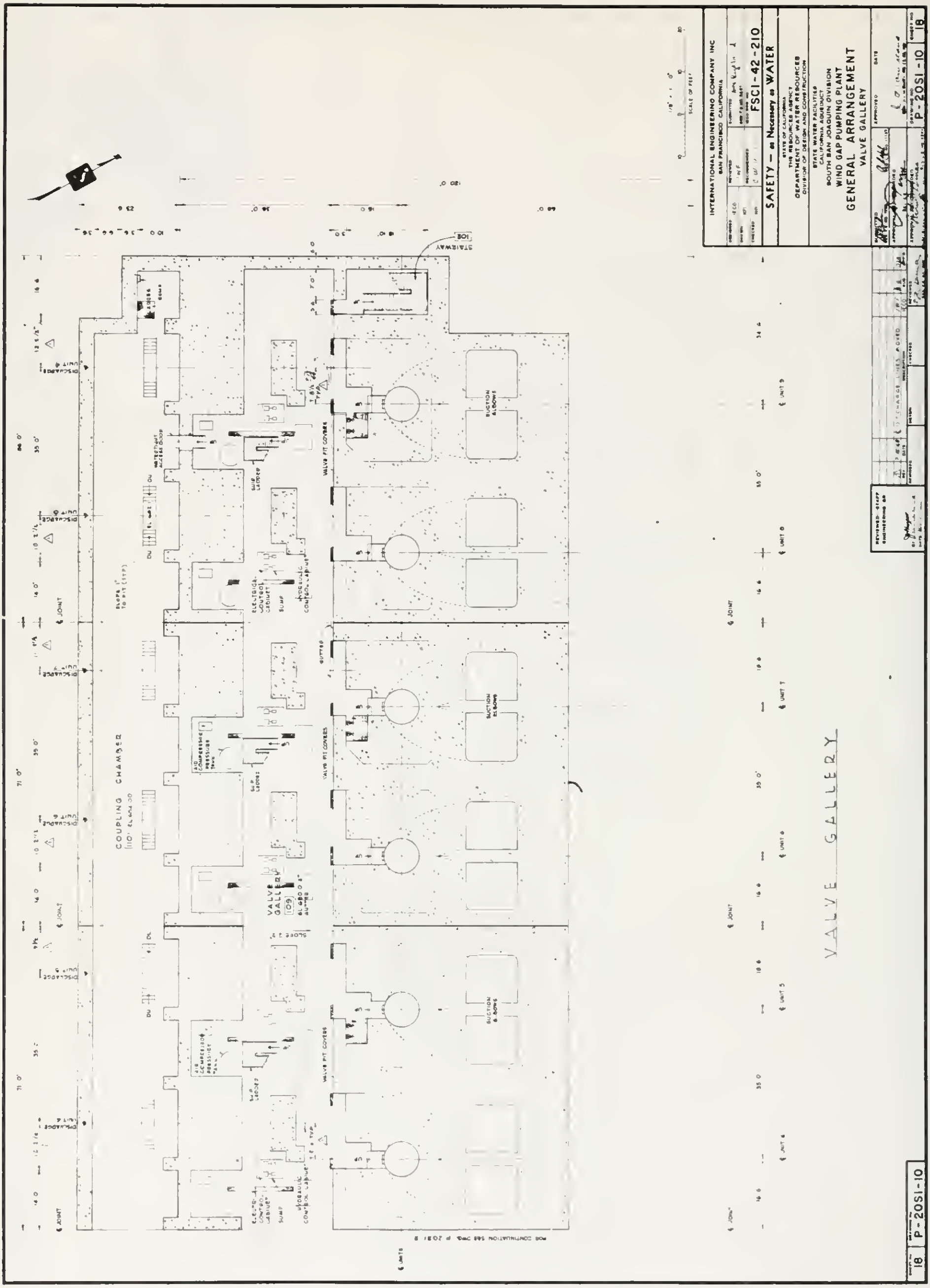

Figure 524. General Arrangement—Valve Gallery

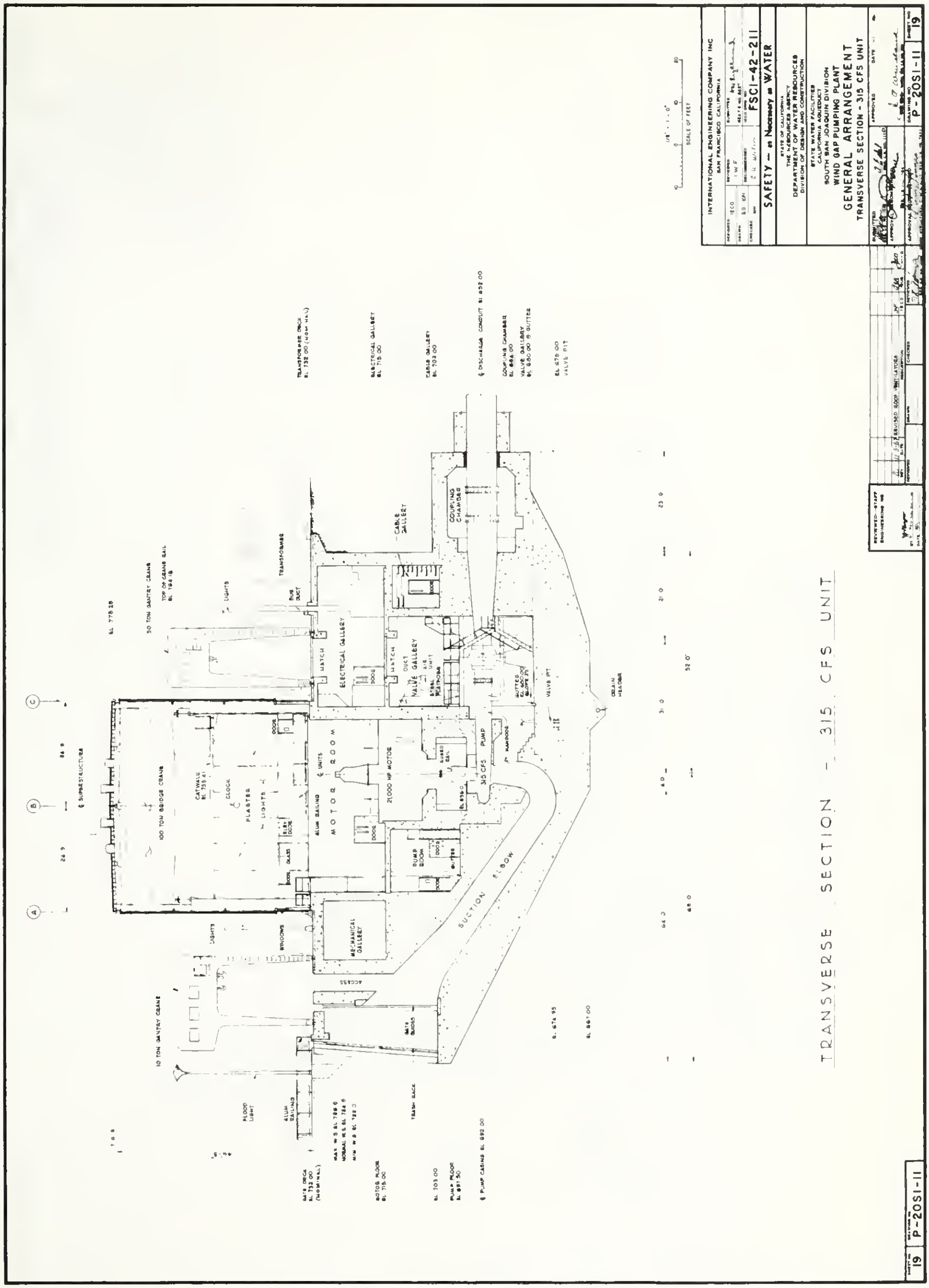

Figure 525. General Arrangement—Transverse Section—315-cfs Unit

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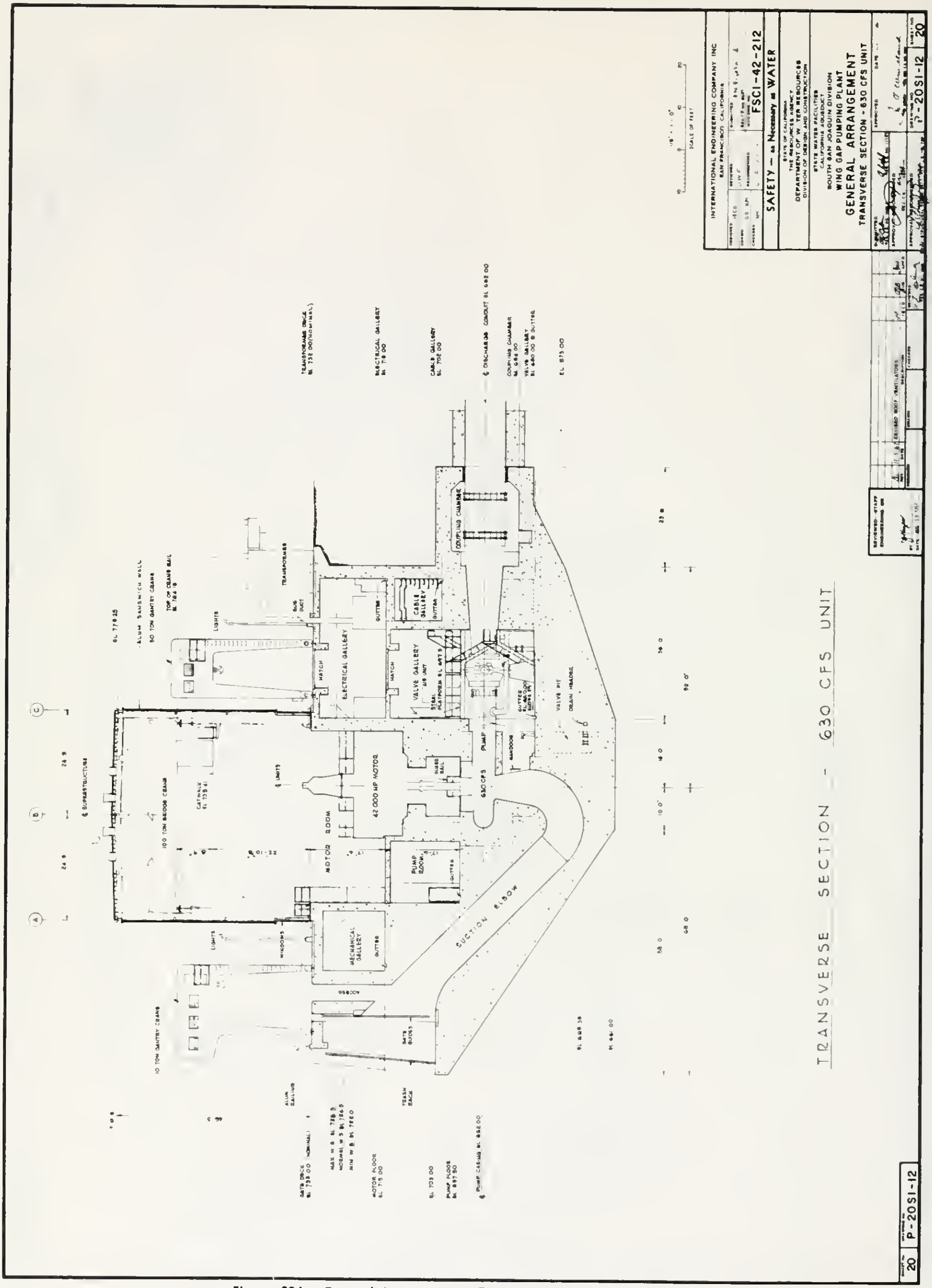

Figure 526. General Arrangement—Transverse Section—630-cfs Unit

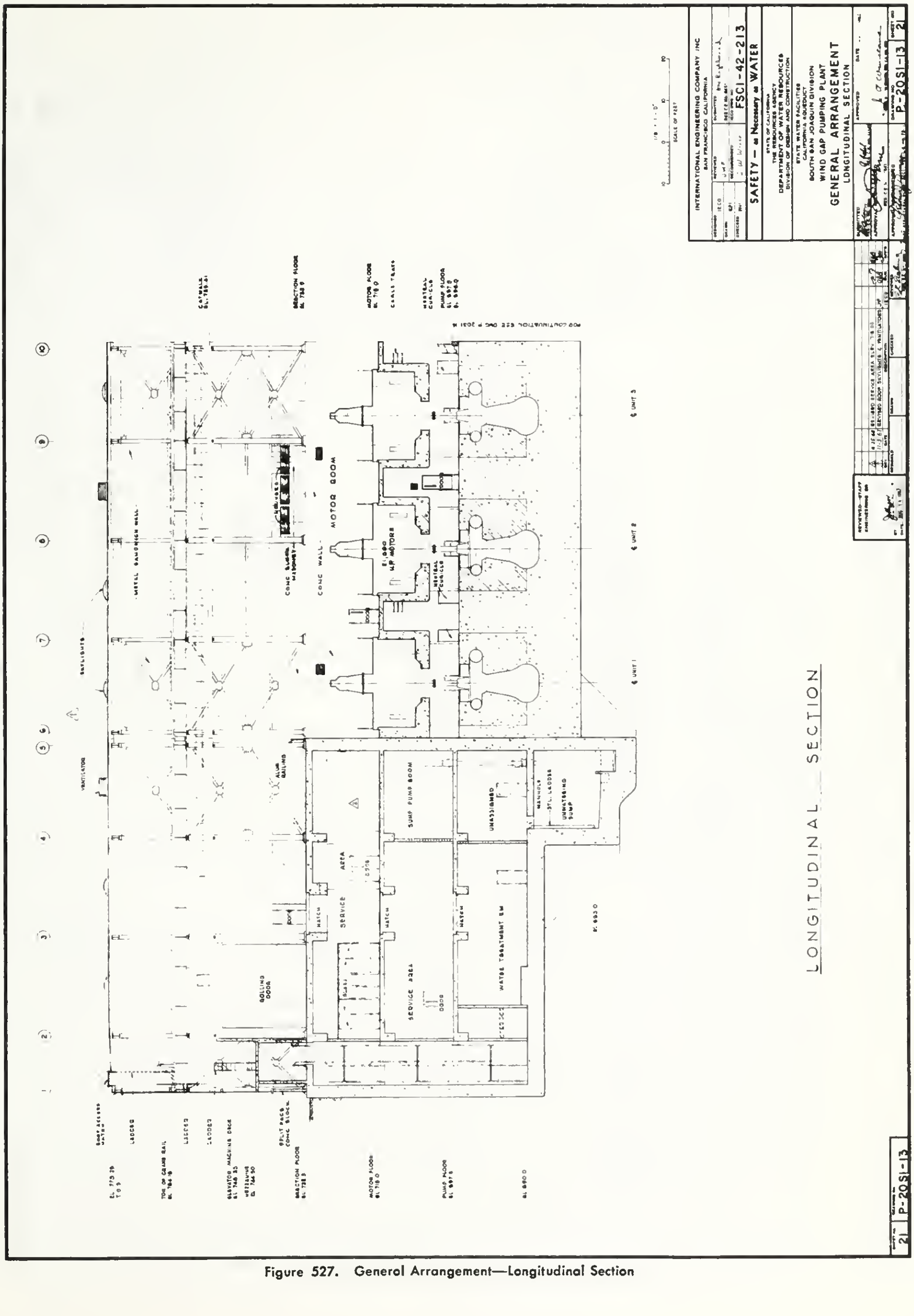

Figure 527. General Arrangement—Longitudinal Section

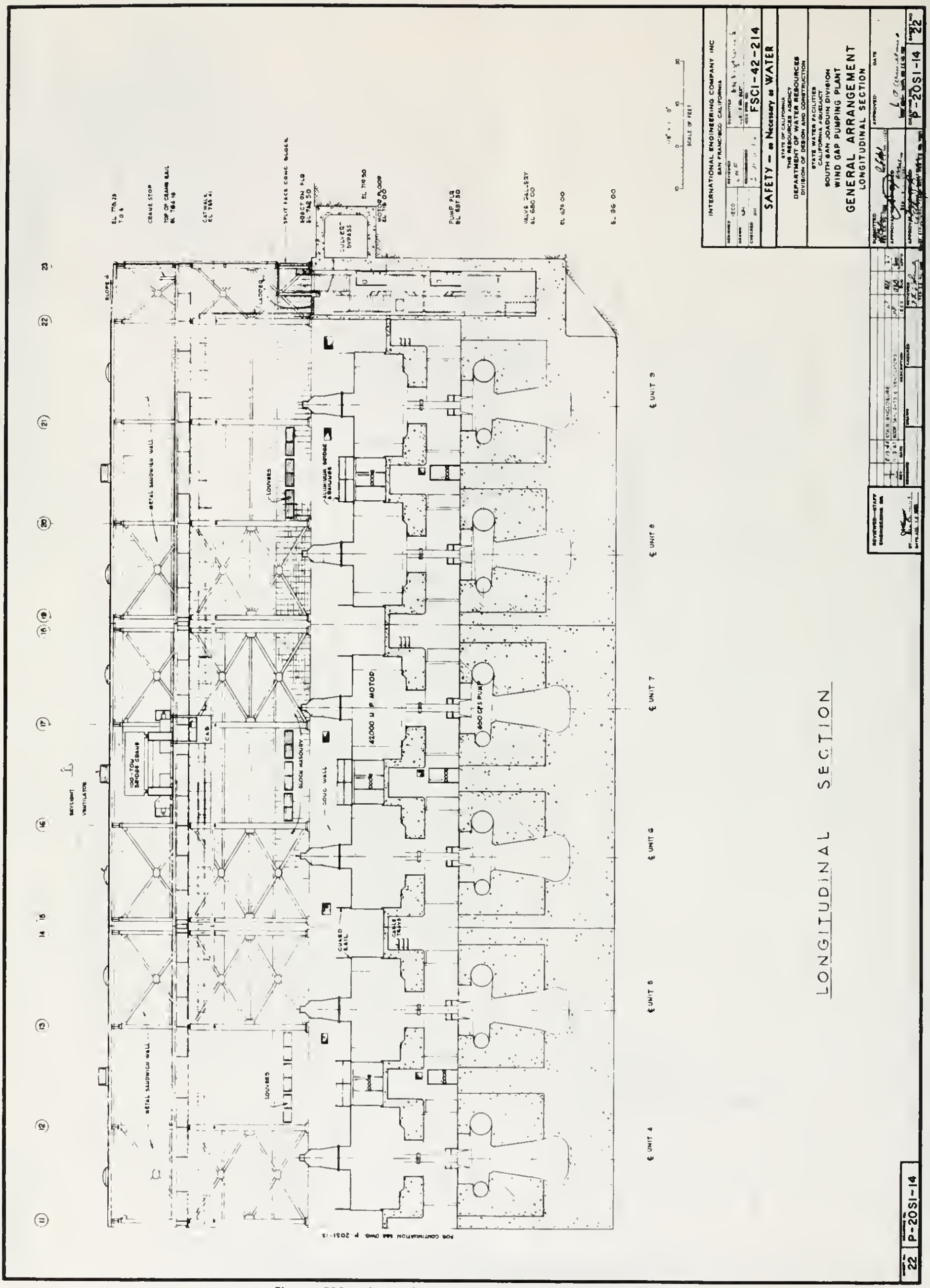

Figure 528. General Arrangement—Longitudinol Section

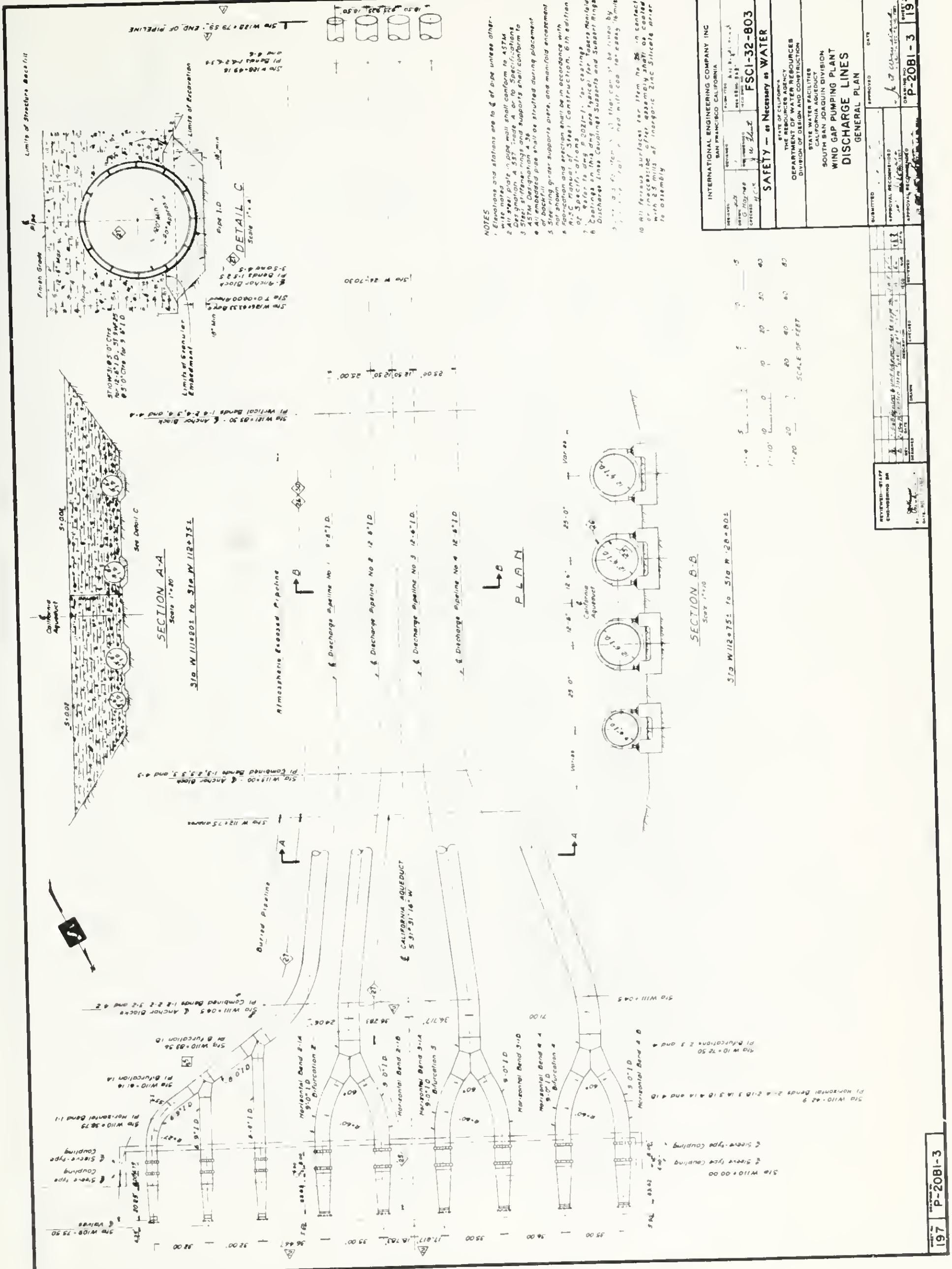

Figure 529. Discharge Lines—General Plan

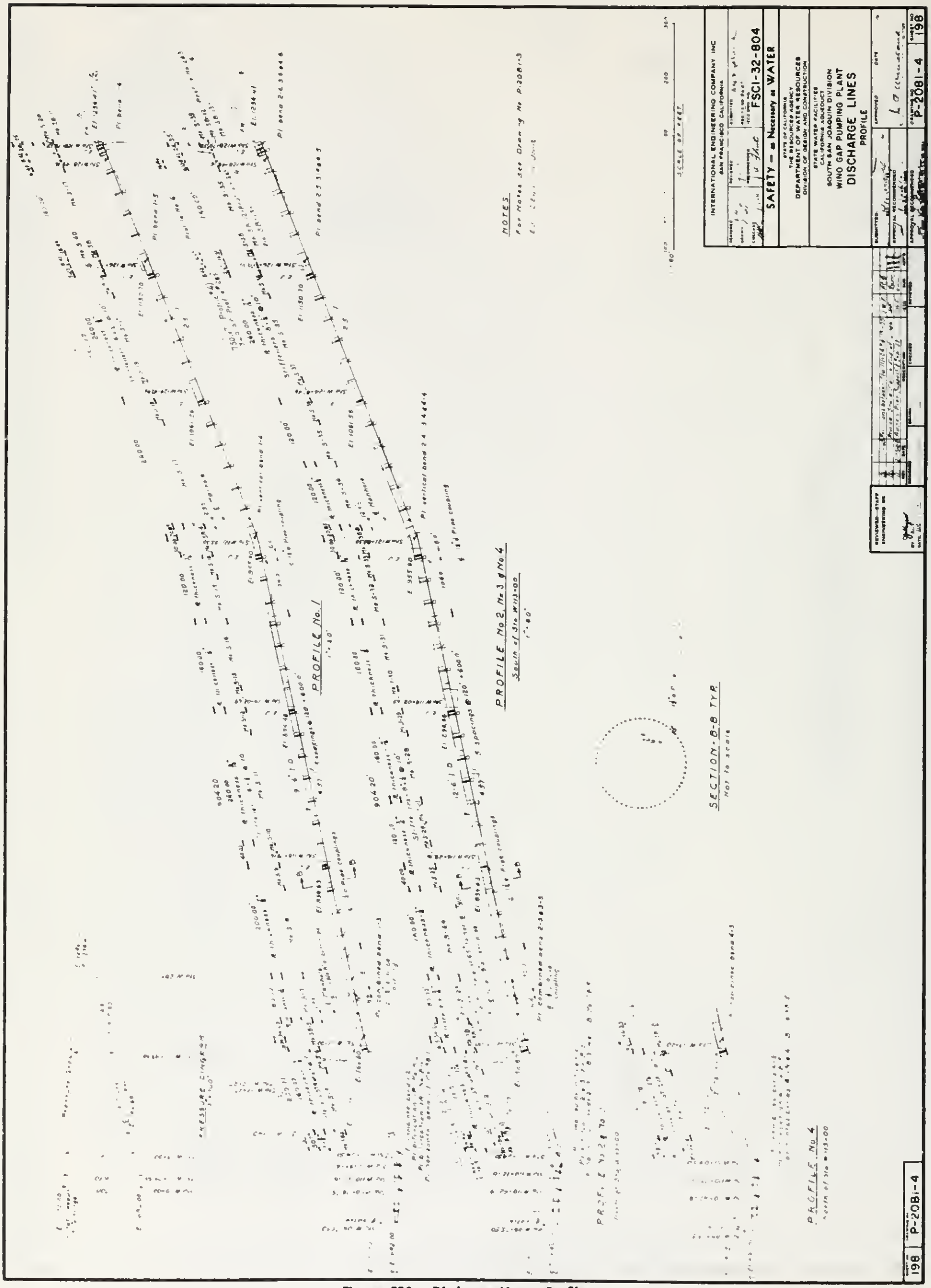

Figure 530. Discharge Lines—Profile

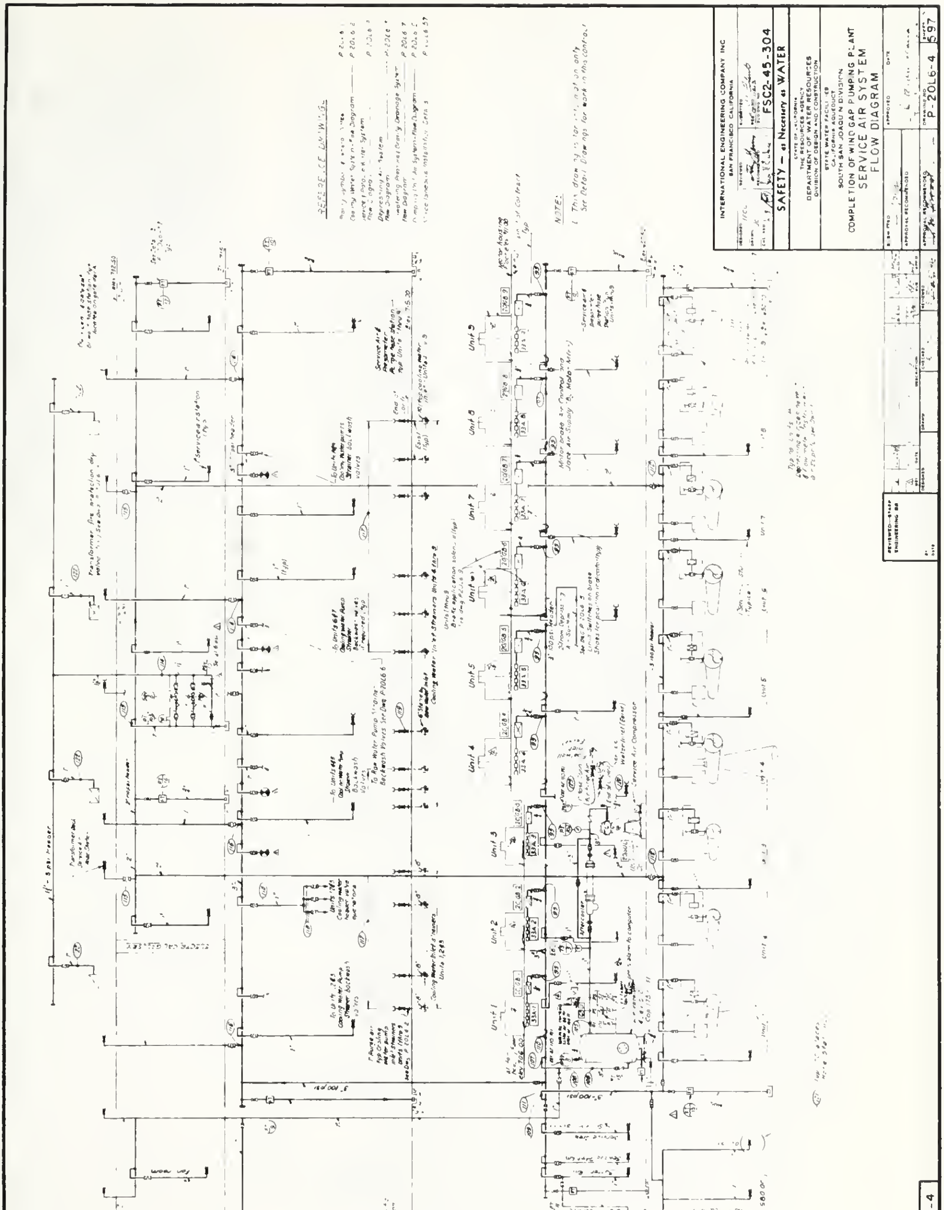

Figure 531. Service Air Diagram

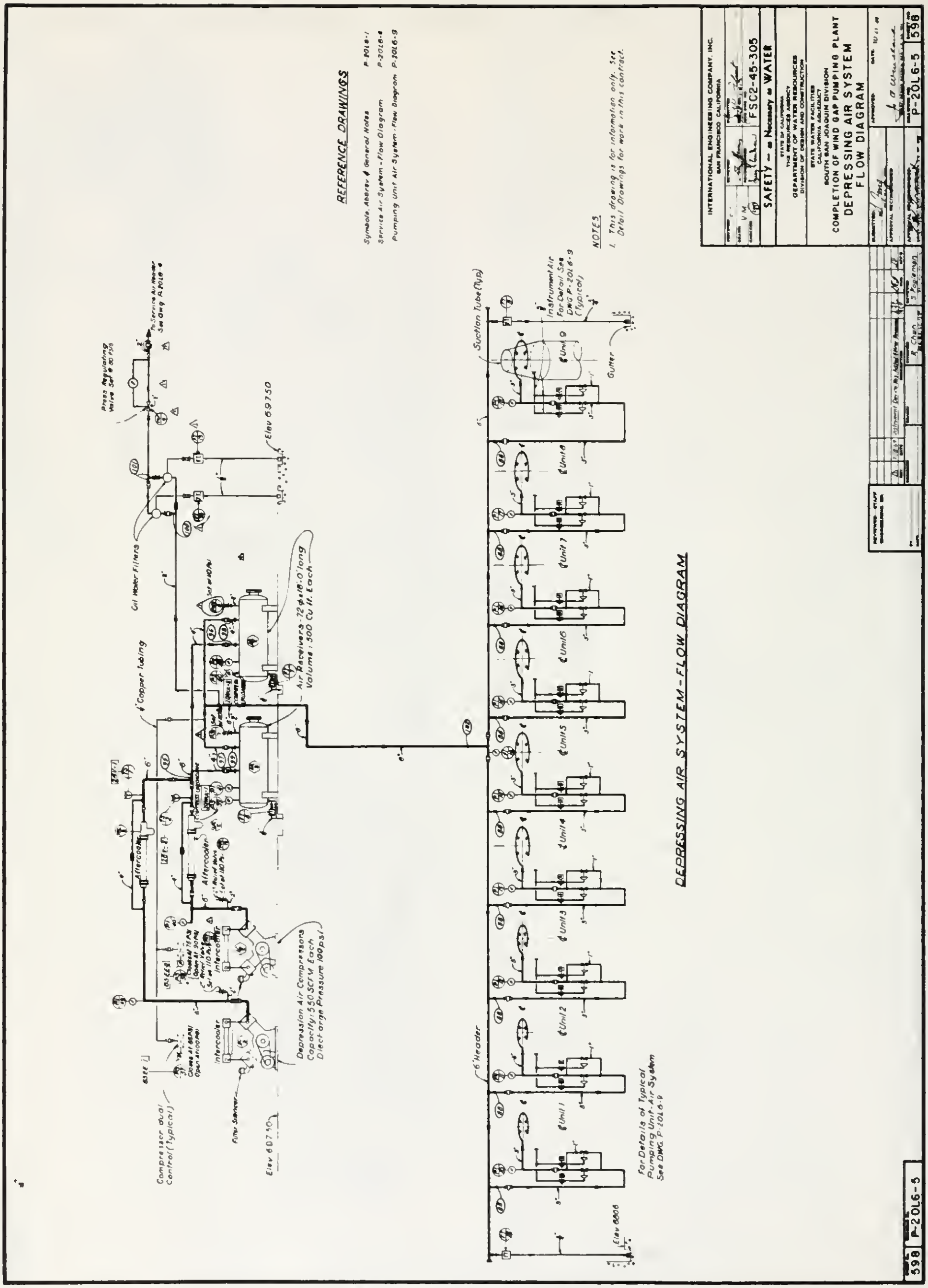

Figure 532. Depressing Air System

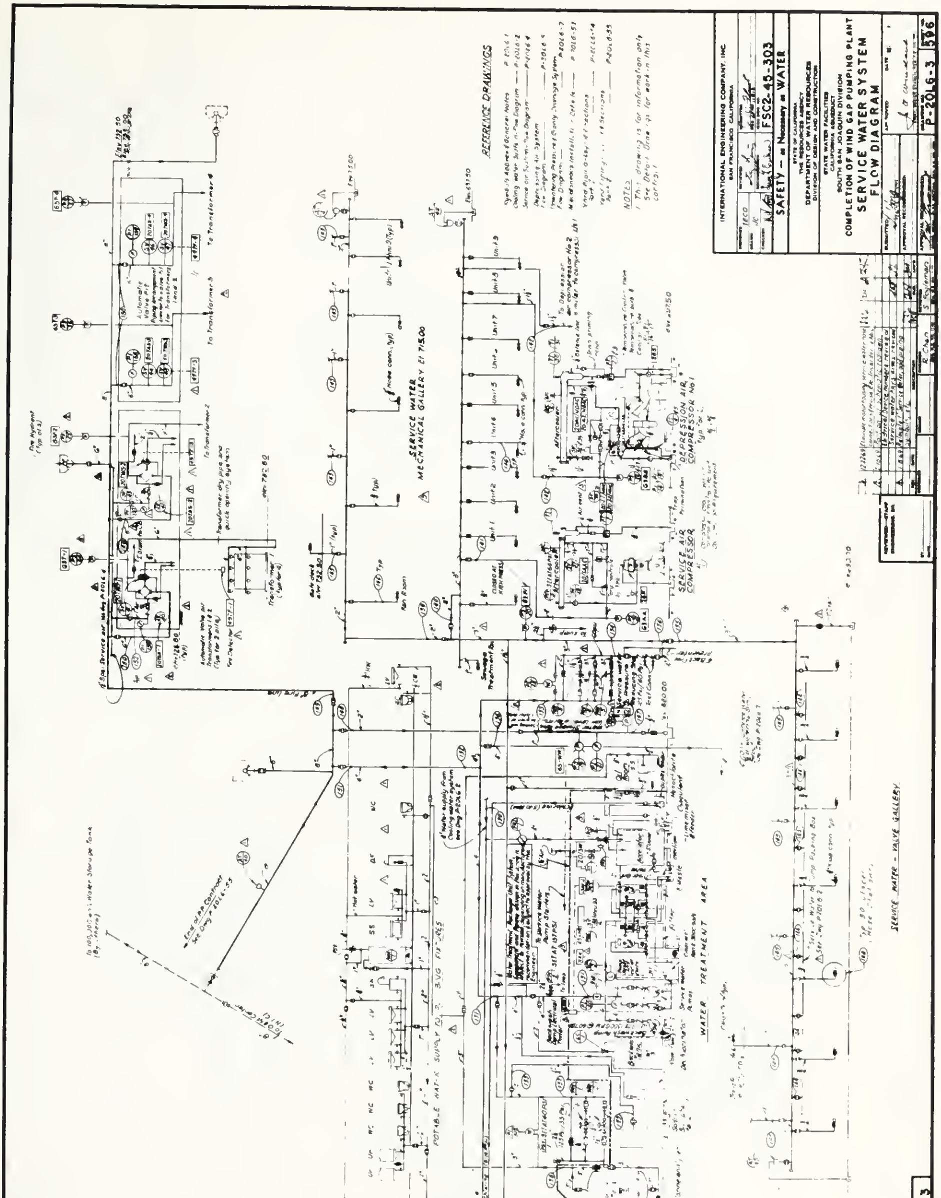

Figure 533. Service Water System

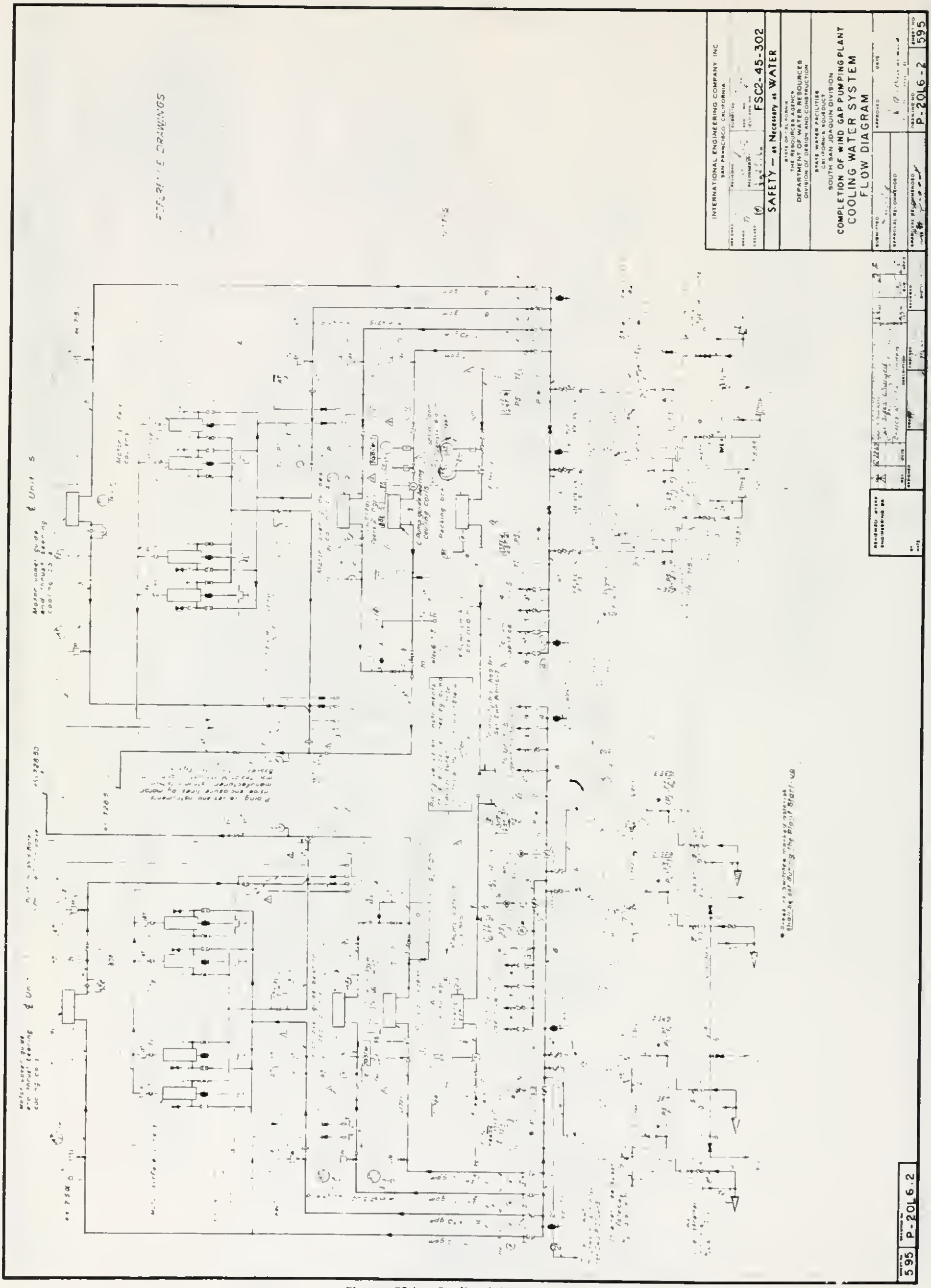

Figure 534. Cooling Water System

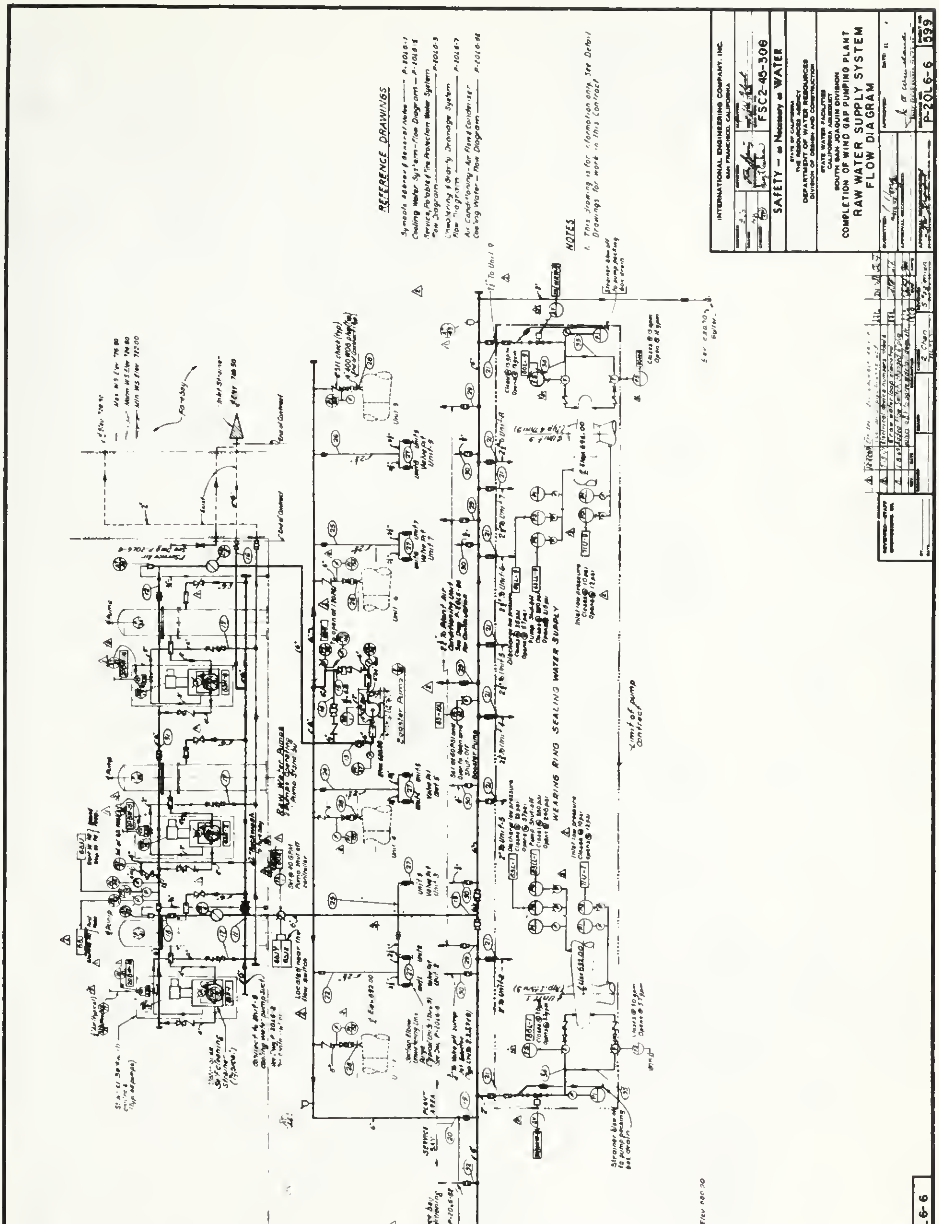

Figure 535. Raw Water Supply System

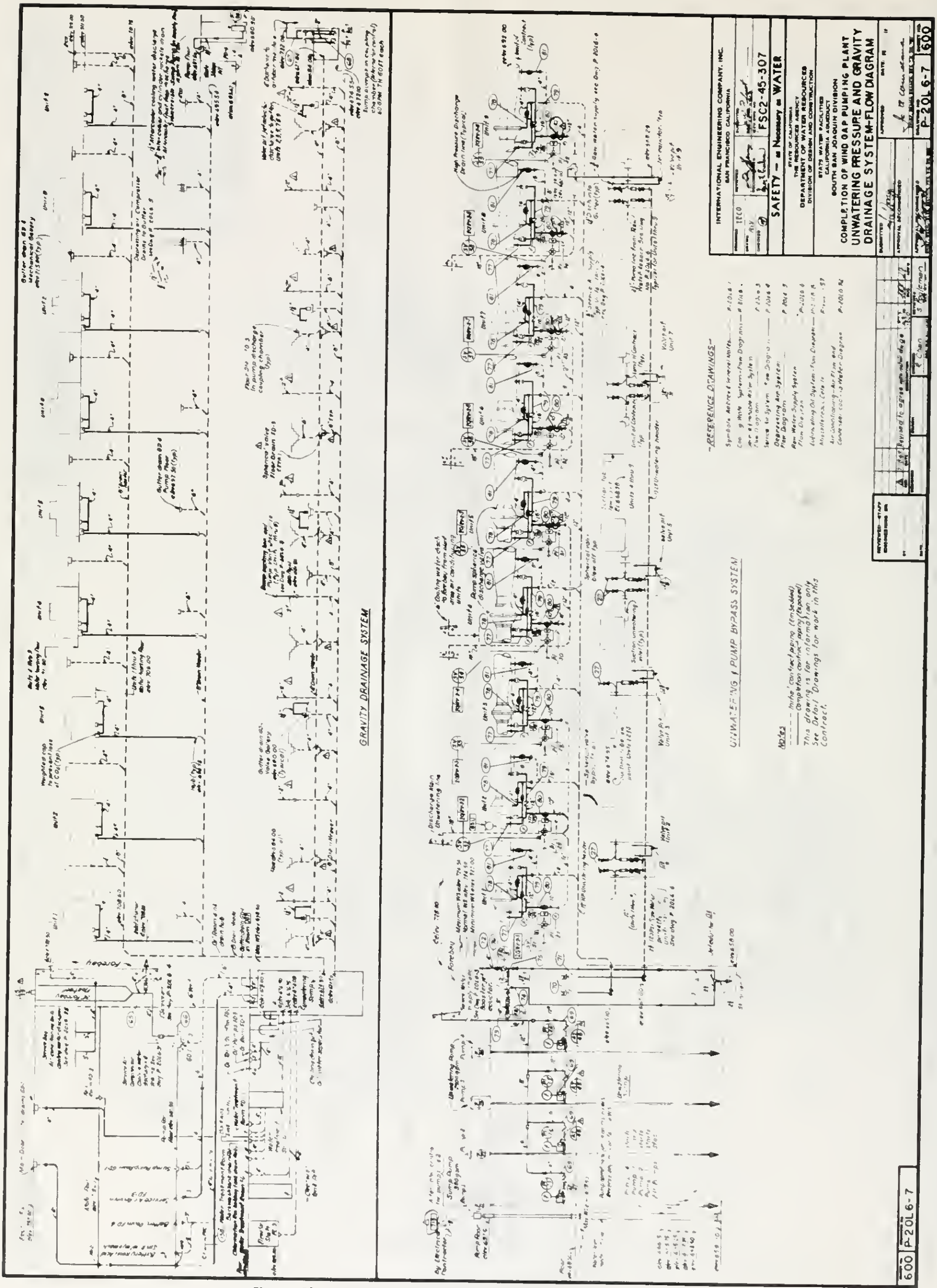

Figure 536. Dewatering Pressure and Gravity Drainage System

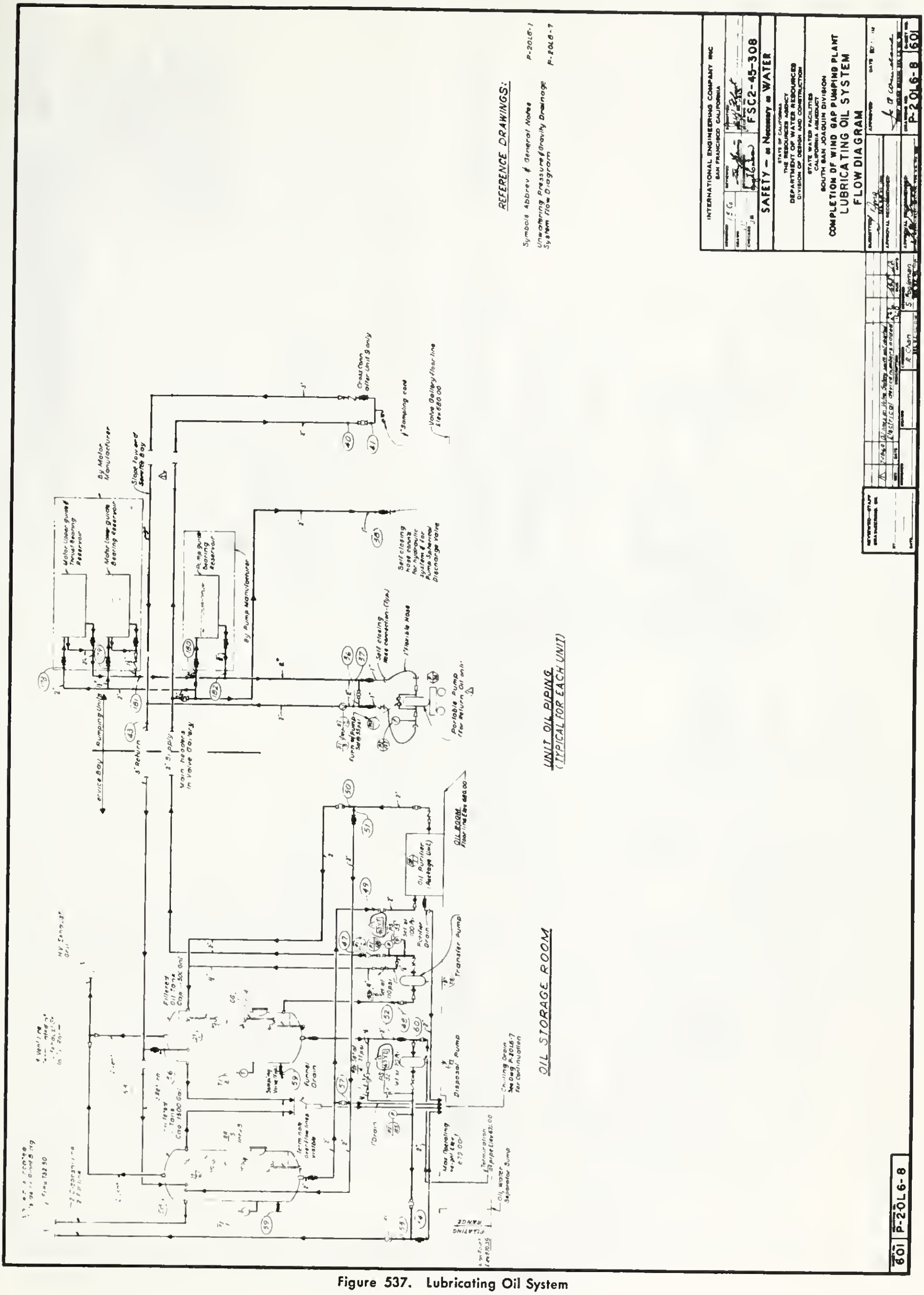

Figure 537. Lubricating Oil System

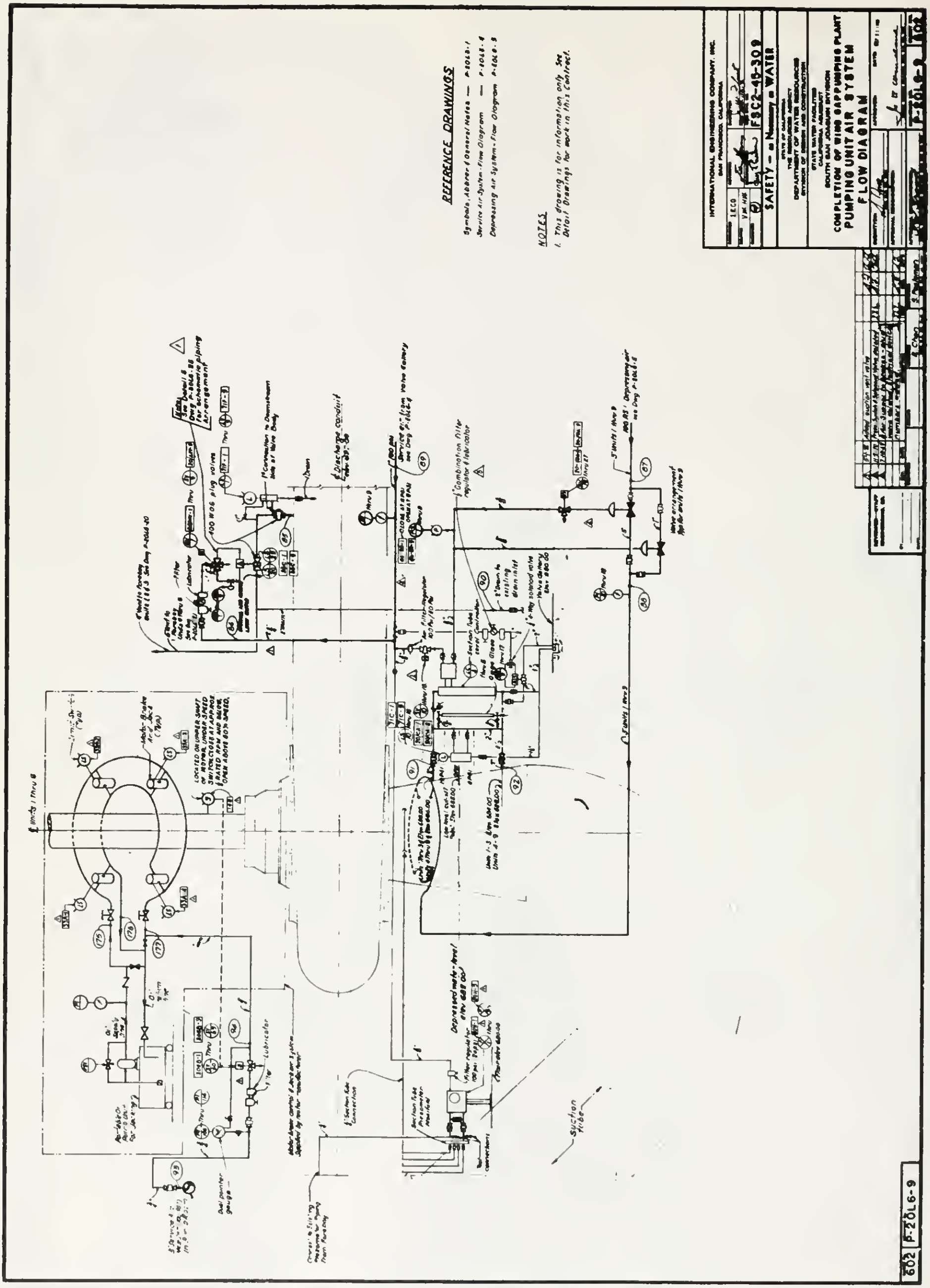

Figure 538. Pumping Unit Air System

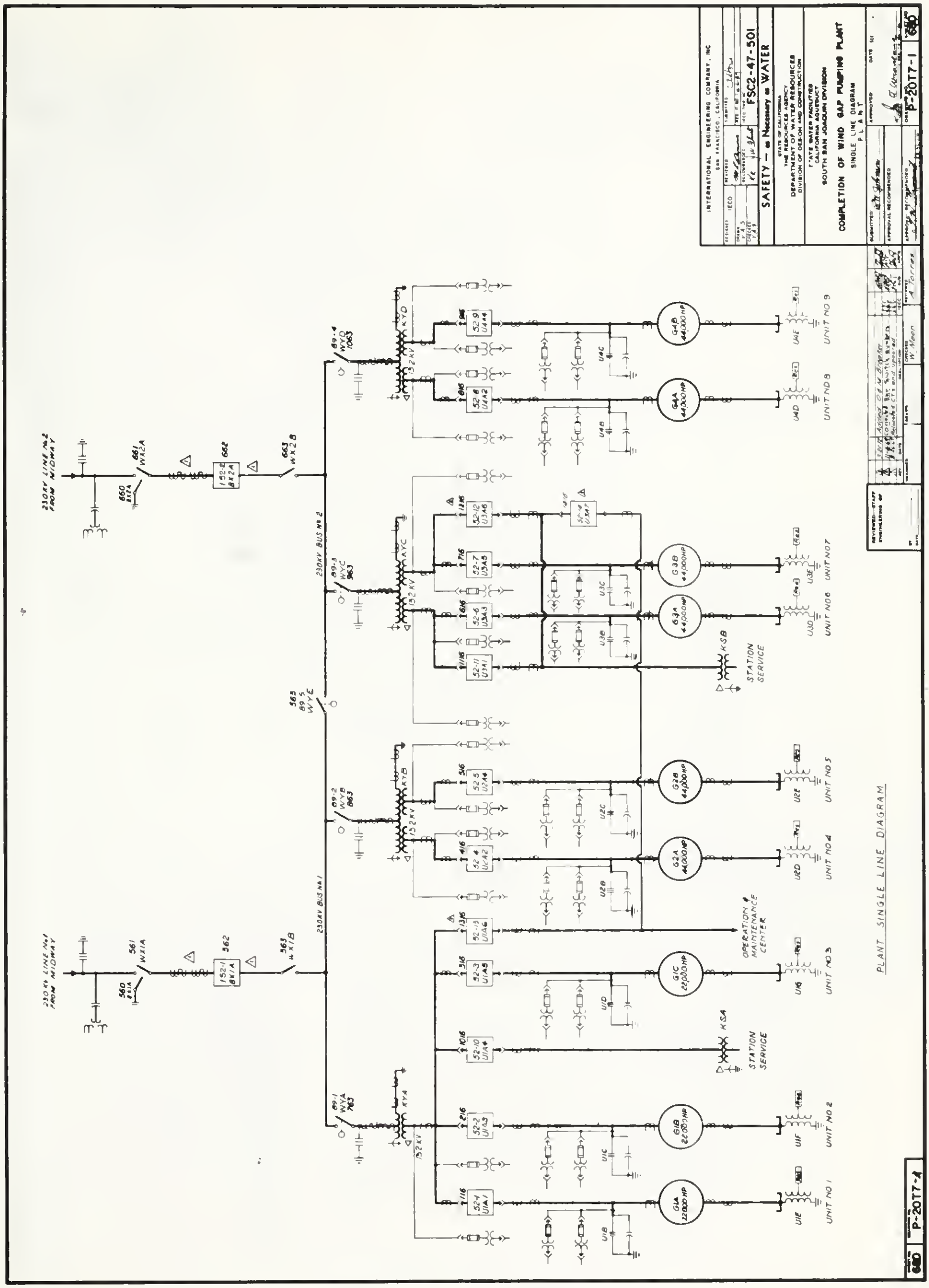

Figure 539. Plant Single-Line Diagram

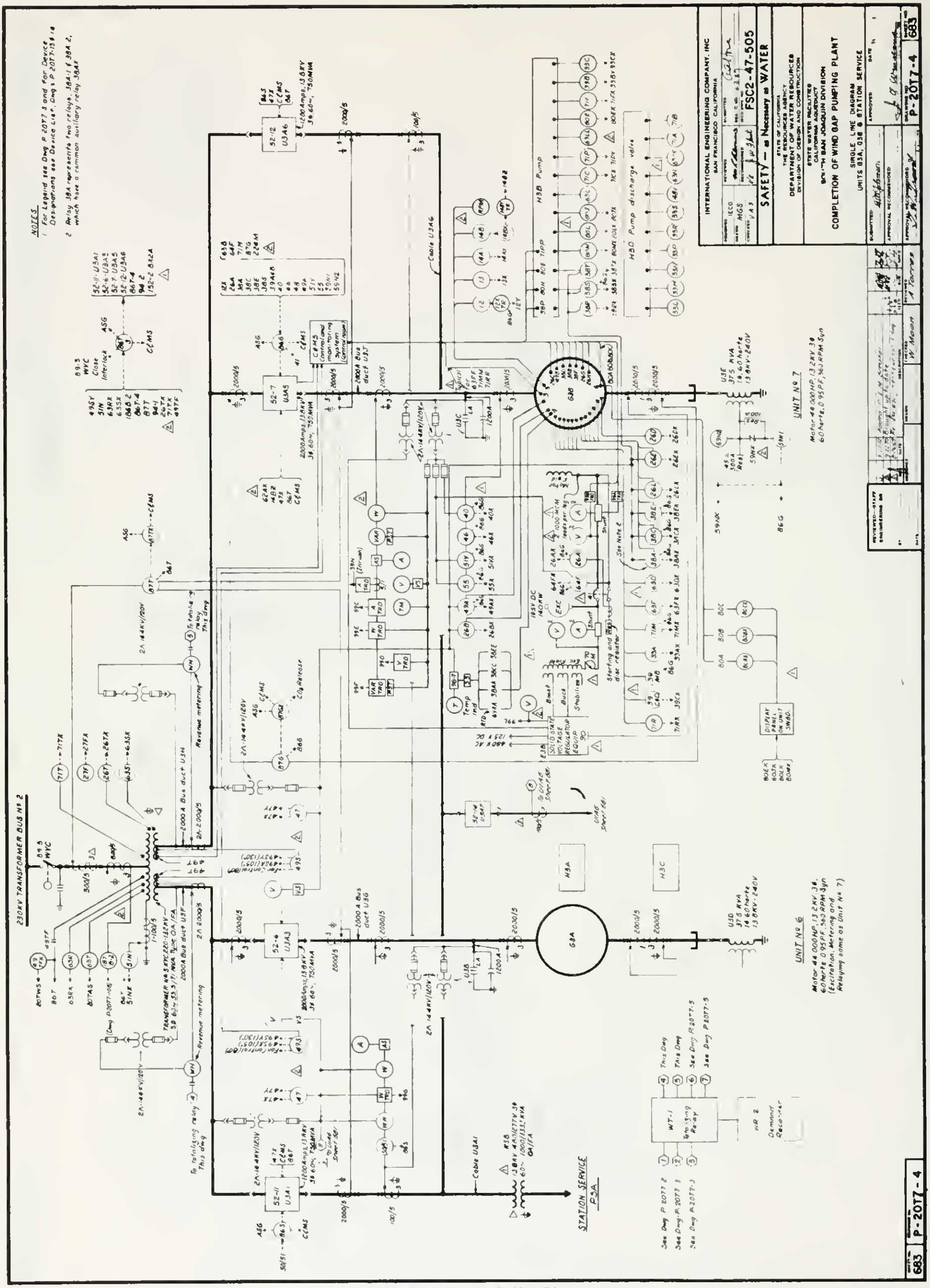

Figure 540. Unit Single-Line Diagram

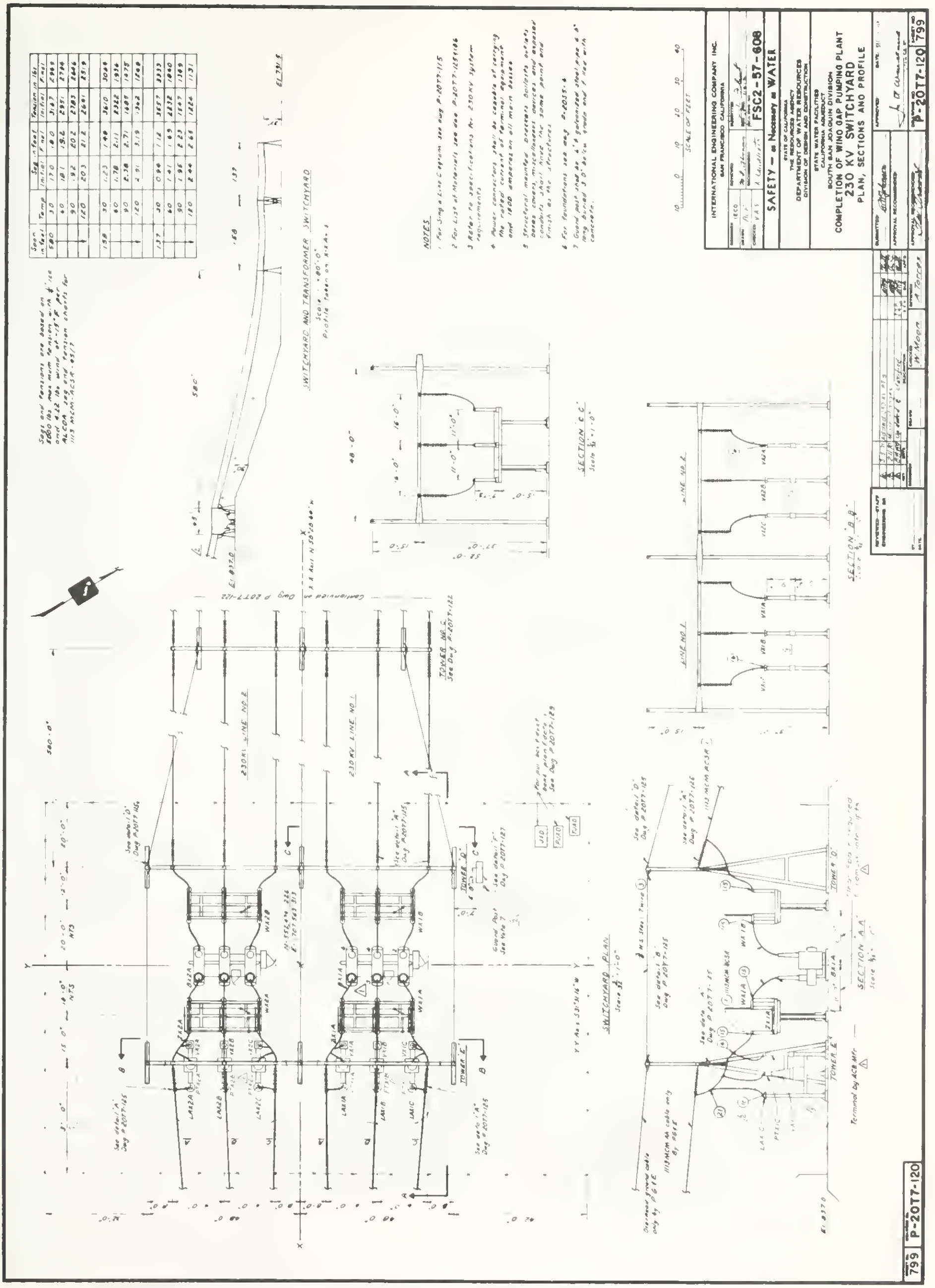

Figure 541. 230-kV Switchyard

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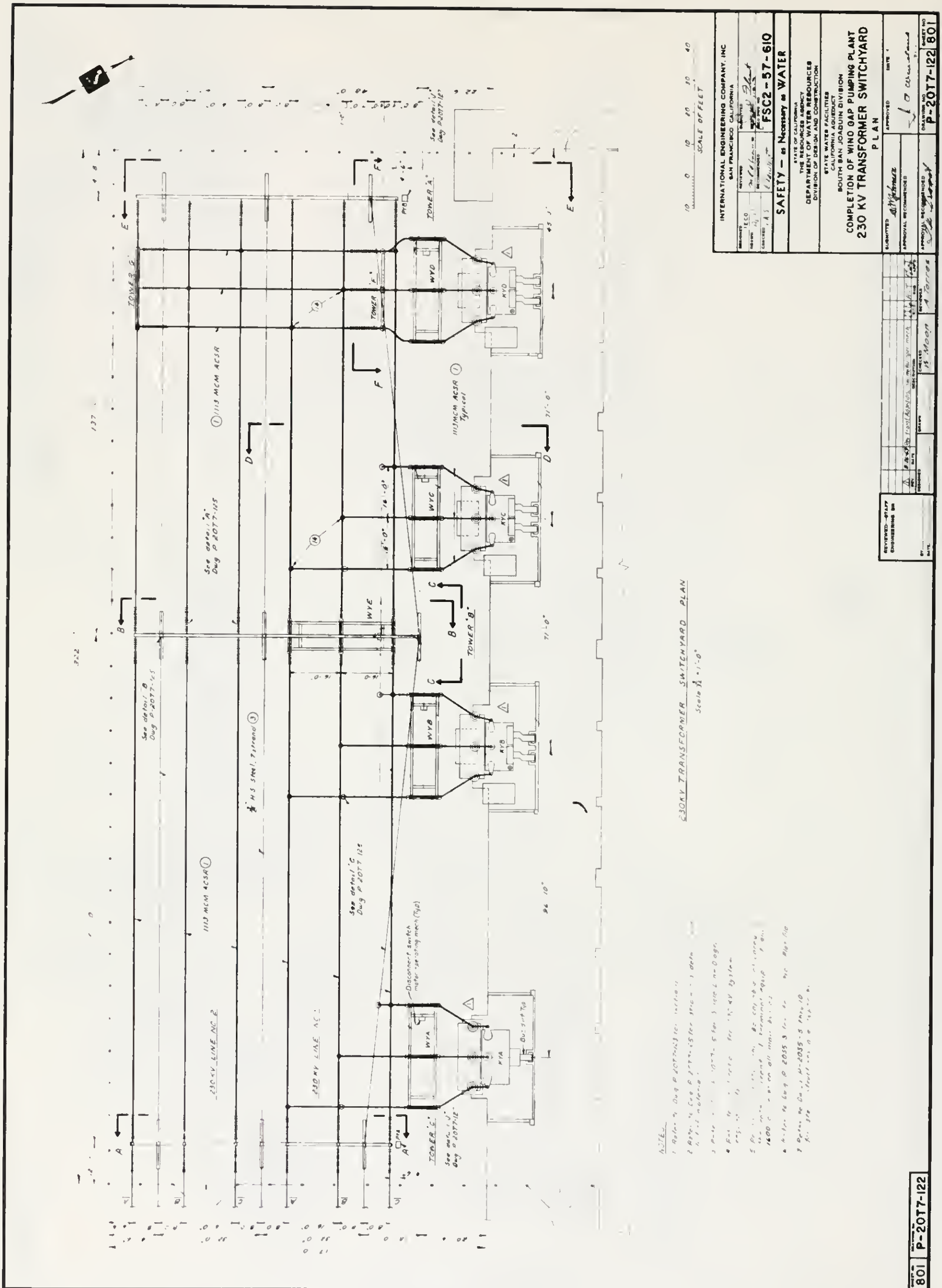

Figure 542. 230-kV Transformer Switchyard

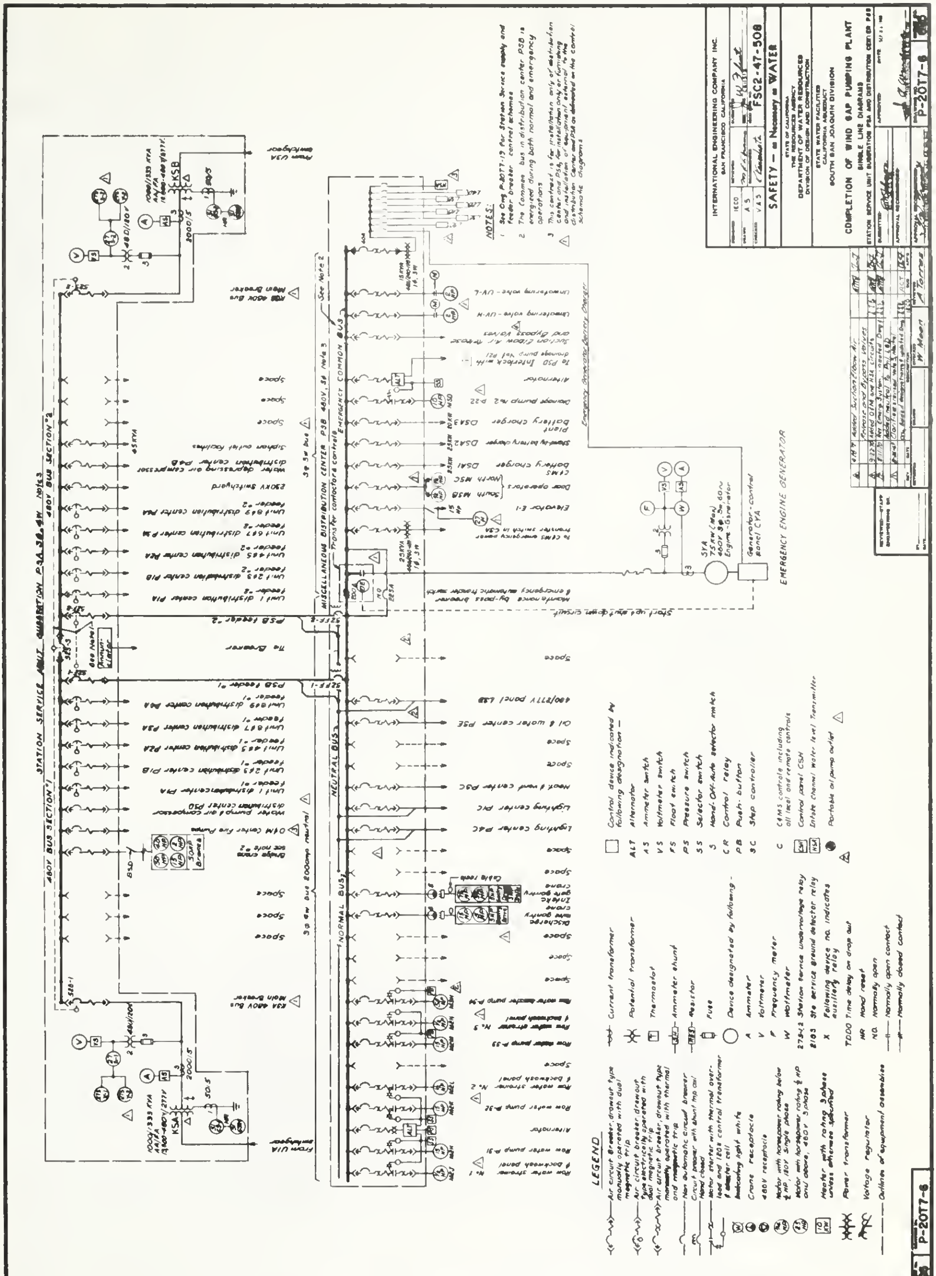

Figure 543. Statian Service Single-Line Diagram

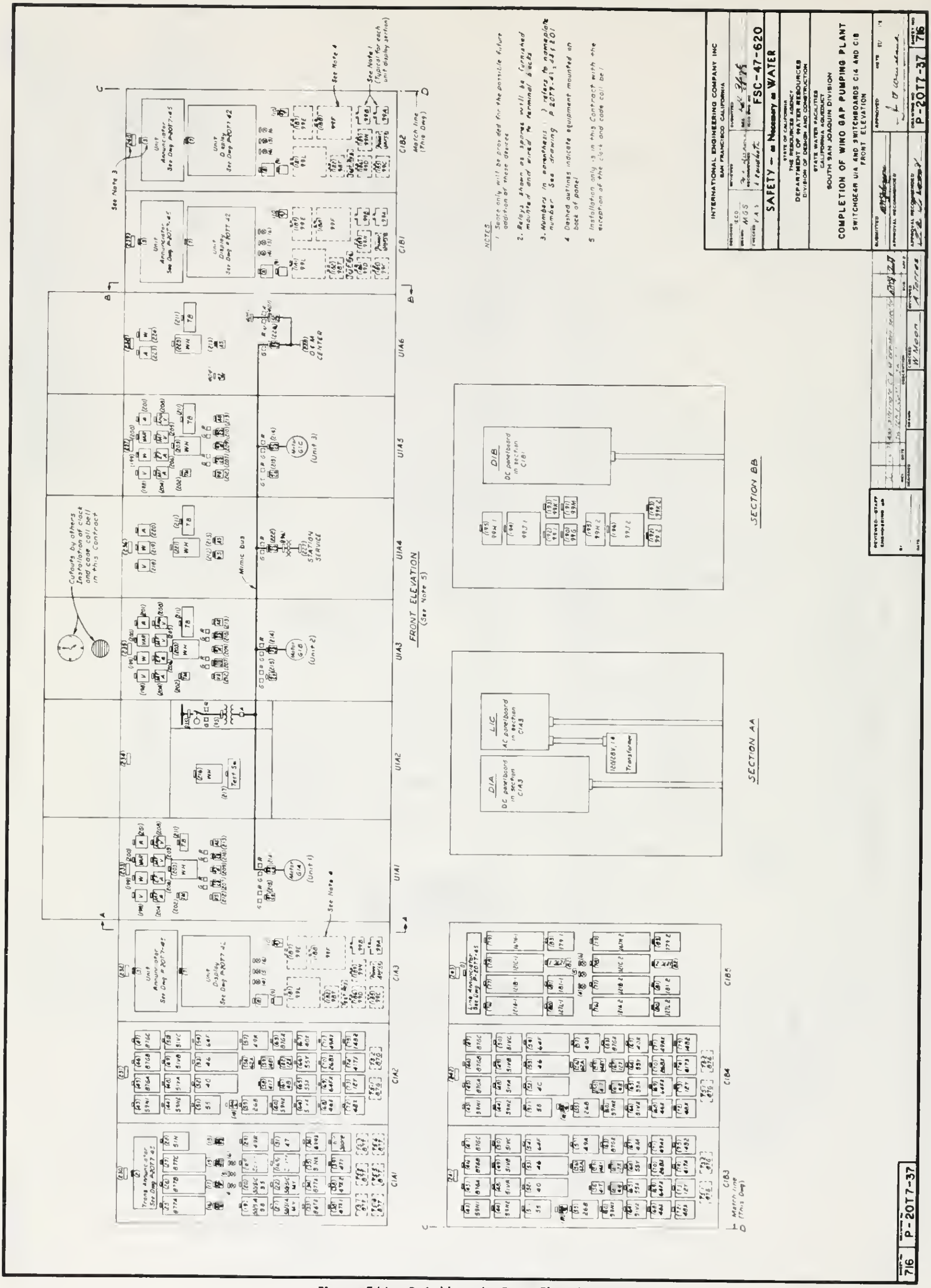

Figure 544. Switchboard—Front Elevation

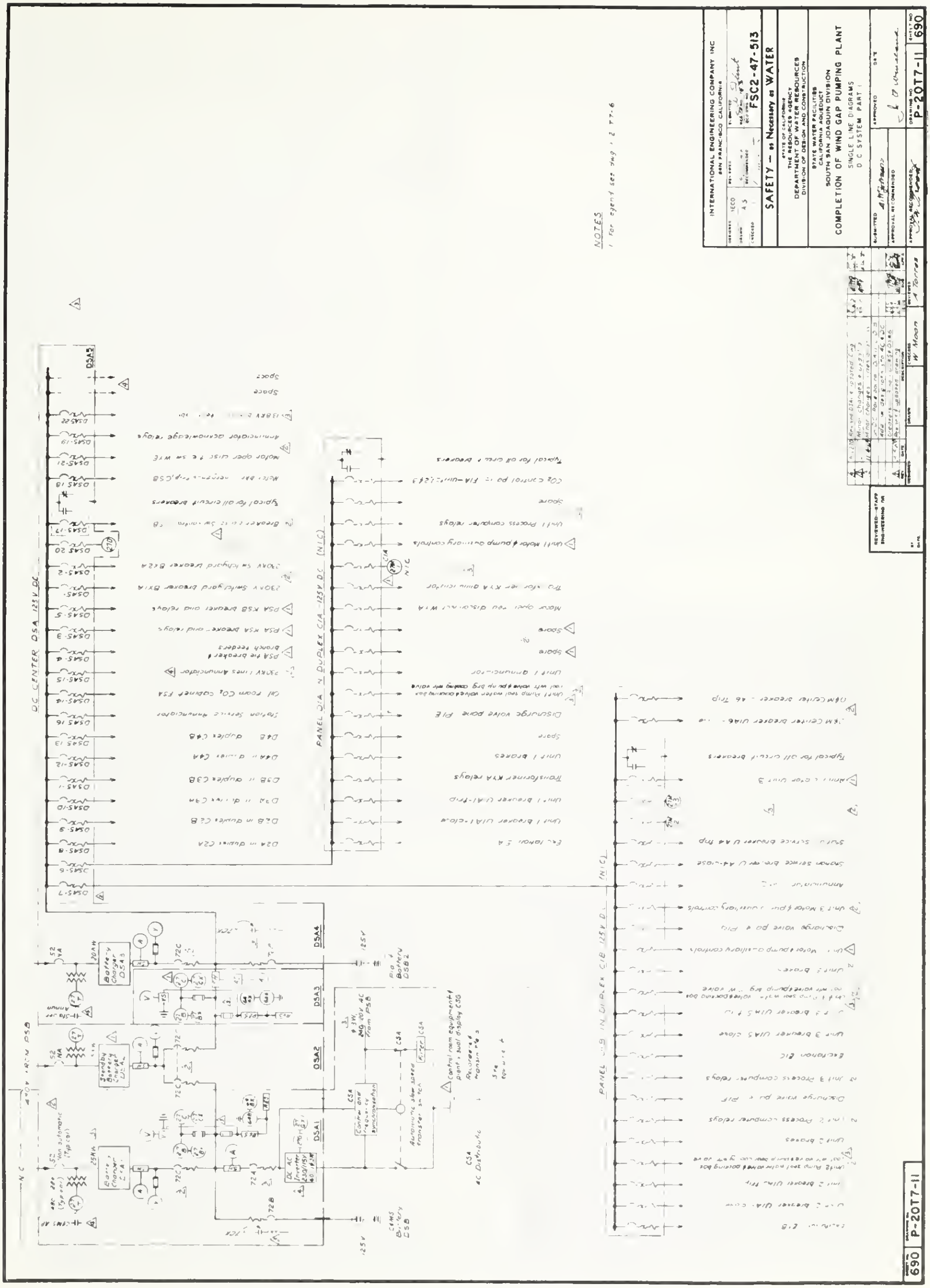

Figure 545. Single-Line Diagram—Direct-Current System

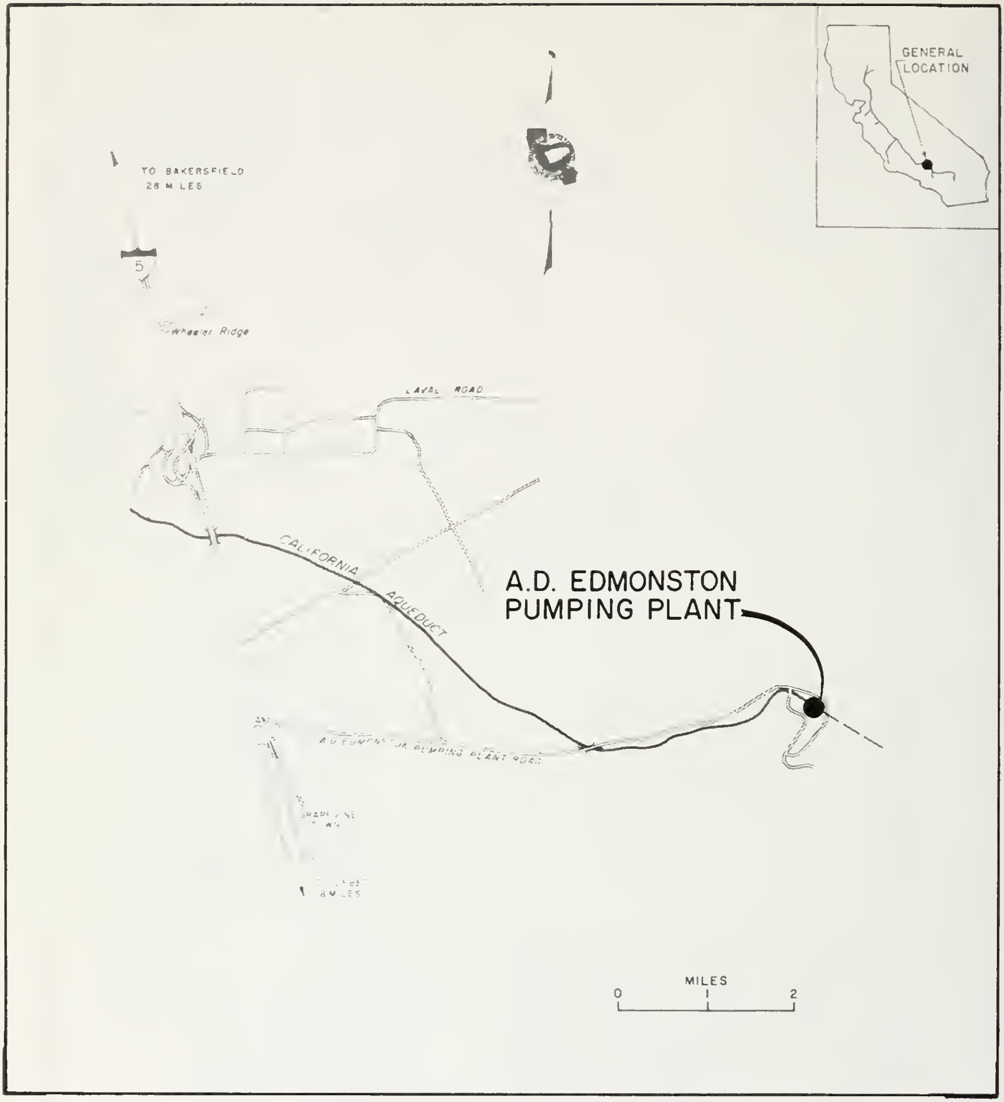

Figure 546. Location Map—A. D. Edmonston Pumping Plant

CHAPTER XIII. A. D. EDMONSTON PUMPING PLANT

General

Location

A. D. Edmonston Pumping Plant, formerly called Tehachapi Pumping Plant, is located in Kern County approximately 30 miles south of Bakersfield and 6 miles east of Interstate Highway 5 (Figures 546 and 547). Access to the site is by A. D. Edmonston Pumping Plant Road, which begins at the Grapevine exit from Interstate 5 (Figures 546 and 548). The plant was constructed during the period from 1967–1973.

Purpose

The Tehachapi Mountains form a major barrier in the transportation of water from the San Joaquin Valley southward into Southern California. A. D. Edmonston Pumping Plant provides the main lift to move water across these mountains.

Description

A. D. Edmonston Pumping Plant will contain 14 four-stage centrifugal pumps. To date (1974), 11 pumps have been installed. Each pump has a capacity of 315 cubic feet per second (cfs) at a dynamic head of 1,970 feet and is driven by a 600-rpm 80,000-horsepower (hp) motor. The remaining three pumps are scheduled to be operational in 1983. At full capacity, 14 pumps will supply 4,410 cfs. Each pump has a single-entrance intake, a steel trashrack, a single-intake gate, and a 48-inch spherical valve which is on the discharge side of the pump.

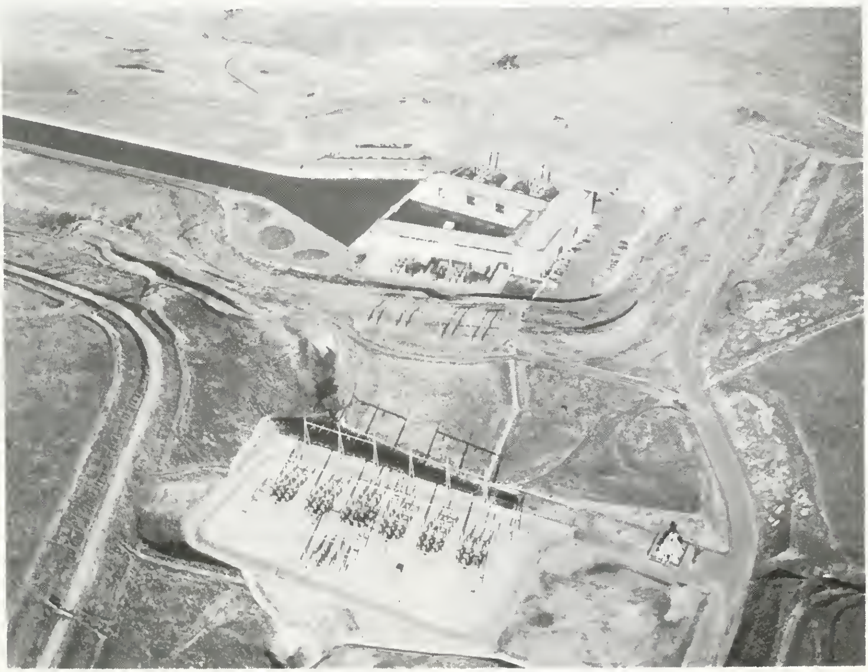

Figure 547. Aerial View—A. D. Edmonston Pumping Plant

Figure 548. Closeup of A. D. Edmonston Pumping Plant

Figure 549. Interior of East Wing

The plant is "U"-shaped with the wings diverging upstream at 7 degrees from the centerline of the structure. The forebay includes a flared section of canal with the area enclosed on three sides by the plant structure. The east wing of the plant contains seven pumps (Figure 549), while the west wing has four of the scheduled seven installed. Water is pumped from the forebay into a concrete-encased steel manifold located along the outer wall of each wing. Two manifolds, one in each wing, connect to twin, underground, discharge lines.

At the downstream end of the plant are two service bays and a motor-generator bay. The latter contains two 35,000-hp motor-generator sets used to start the pump motors. Representative drawings are included at the end of this chapter.

Geology

Areal Geology

Tilted, Tertiary, sedimentary rocks are present along both the northwest and southeast margins of the Tehachapi Mountains. The central mountain mass is made up of a crystalline complex. The crystalline rocks include a number of elongated bodies, up to several miles in length, of metamorphic and igneous rocks.

The most common and areally extensive rocks in the Tehachapi Mountains are the intrusive types. These range in composition from granite through gabbro with an average composition in the range of diorite. The metamorphic rock types include gneiss, schist, phylite, slate, and marble.

Site Geology

Recent alluvial fan deposits of coarse-grained silty gravelly sand, plastic clay, and boulders covered the site. The boulders, although widely scattered throughout the alluvial deposits, appear to have concentrated in two specific locations: at the base of the alluvium and near the surface, especially along the east side of the small valley in which the plant is located.

Tejon formation forms the main part of the foundation for the Pumping Plant. The formation is mostly massive, gray, silty, sandstone beds with thin interbeds of dark shale. Tecuya formation overlays the Tejon formation and is both alluvial fan and shallow water deposits interbedded with volcanic dacite, basalt, and agglomerate. Crystalline rocks, mainly quartz diorite and diorite gneiss, make up the foundation on the back slope of the plant and underlay the service bay motor-generator area and the discharge lines.

Sandstone and shale in the foundation slake when exposed to the air, and a protective coating of shotcrete was applied to the sedimentary rocks within 24 hours of exposure to the air. In addition, all shattered, loose, disintegrated, and/or sheared and hydrated rock was overexcavated.The thin sandstone wedge at the contact with the crystalline rocks also was overexcavated so that the minimum thickness of sandstone was 5 feet. All areas of overexcavation were backfilled with shotcrete or concrete.

Slope failure occurred at several locations. Landslides developed where joint planes, bedding planes, and highly fractured rock intersected along the southwest slope. During the late stages of excavation of the plant site, a large rock mass over the portal area of the discharge lines slid from the southeast slope along a prominent joint plane. It was apparent that unless slopes were stabilized, rock falls over the portals for the discharge lines would be a hazard to personnel, and slope failure could block the tunnel entrances. Therefore, steel reinforcing bars were grouted into the slope, and these areas were secured with chain-link fabric and gunited.

Subsequent to the corrective work, a rock fall occurred in the southeast corner adjacent to the area which had been reinforced with steel bars. The base of the failure was the prominent joint plane which also was the failure plane of the first slide. The back plane of the rock fall was a shear zone in the quartz diorite.

Unstable biotite schist and sheared rock were present in the south wall of the west sump. The condition was corrected by resloping and reinforcing the rock with rock bolts, chain-link fabric, and gunite. Diorite gneiss in the south wall of the east sump appeared to be stable until a large wedge of rock slipped out. Failure occurred along three intersecting shear planes. Rock bolts, chain-link fabric, and gunite were used to stabilize the area until concrete was placed. During excavation of the west wing, a shear zone was uncovered which dipped into the north wall of the west sump. This wedge was overexcavated and backfilled with concrete.

Total flow of ground water into the plant excavation was low. Dewatering was accomplished with sump pumps and piping the water from the area.

The ridge selected for the plant discharge line alignment is an anticlinal structure with a central core of quartz diorite with diorite gneiss and mica schist on the flanks and uppermost crest. Foliation parallels the rock structure and dips steeply to the northeast. The major structural trend is complexly faulted, and the entire area is a complexly folded and faulted assemblage of metamorphic rock.

The discharge tunnels were excavated entirely in crystalline rock of the diorite complex. Horizontal reaches of the discharge line tunnels were excavated full-face. The two upper incline reaches of the tunnels were excavated using pilot shafts, which were drilled by a raise drill. Pilot holes 9⅝ inches in diameter were drilled from the upper portals to intersect the horizontal tunnels, and the holes were back-reamed using a 6-foot-diameter reaming bit. The shafts then were enlarged to full size by drilling and blasting. The lower incline shafts were excavated by sinking shafts.

Geologic Exploration

Exploration for the Pumping Plant consisted of rotary core holes, adits, and geophysical surveys. Geologic maps were made of the excavation and tunnels. Seismitron listening stations were set up at 109 locations in the four horizontal tunnels, and rock noise was monitored during tunnel construction. Rock mechanic studies for deformation modulus, Poisson's ratio, and rock classification were made in the tunnels using geophysical methods to supplement visual classification.

Instrumentation

A network of slope-indicator casings, rebound gauges, and tiltmeters was installed to monitor slope stability and ground movement during excavation of the plant site and construction of the Pumping Plant. Installation was made prior to the start of construction, and initial readings were made so subsequent movements resulting from construction could be determined.

Slope indicators were installed at three locations around the periphery of the excavation. Regular measurements were obtained from March 1966 until October 1969. The frequency of the measurements varied throughout this period as dictated by the construction activities. Readings were discontinued when the results from the surveys and the status of the construction indicated they were no longer necessary. No significant movements resulting from the site excavation or plant construction were noted in the slope-indicator casings.

To determine the rebound resulting from the removal of nearly 200 feet of soil and rock, eight rebound gauges were installed at the site, six below plant invert elevation and two in the pumping plant pool area. Because of the rock foundation, only a small amount of rebound was to be expected. Under these circumstances, a continuous record of the rebound was not needed, so buried-type gauges were used.

In general, the rebound gauges provided limited information on foundation movements. The data was adequate to show that only a small amount of compression should be expected with the reloading of the foundation by the structure. Structural bench marks installed in the plant later confirmed these findings.

Seismicity

The Pumping Plant and discharge line tunnels are located in a seismically active area. Six major faults and numerous minor faults are within 25 miles of the plant site. Three of these faults, the San Andreas, White Wolf, and Santa Ynez, have been sources of destructive earthquakes within historic times. The remaining three major faults, the Garlock, San Gabriel, and Big Pine, are dominant geologic features in the mountain ranges to the south but historically have not been the sources of damaging earthquakes. Movement of these known faults, as well as movement of lesser known faults, is anticipated and possible damage associated with shaking is expected during the operating life of the facilities.

Civil Features

Preliminary Studies

In the early planning stages, several routes for transporting water through the San Joaquin Valley into the southernmost part of the State were considered. These alternative routes included a direct crossing of the Tehachapi Mountains, an aqueduct through the coastal counties of Santa Barbara and Ventura, and even a submerged offshore conduit parallel to the coast of California. The direct crossing of the Tehachapis was selected as the most reliable and economical.

Recognizing the complexity of design and construction in crossing one of the most active seismic regions of the State, the Department of Water Resources convened two consulting boards: (1) the Tehachapi Crossing Consulting Board, composed of experts with worldwide experience in the field of water conveyance to advise the Department on major features of design and construction; and (2) the Consulting Board for Earthquake Analysis, consisting of foremost experts in this field, to advise on the establishment of earthquake design criteria (see Appendix B of this volume).

Lifting 4,410 cfs of water 1,926 feet was unprecedented in the United States—both in quantity of flow and pump lift. This presented many problems such as type of lift, location, configuration of plant, tunnel alignment, and how and where to cross the Garlock fault.

During the planning stages, three different lift systems were studied—a single lift of 2,000 feet, two lifts of 1,000 feet each, and three lifts of about 670 feet each.

Results of these studies indicated that pumps required for each of these systems were feasible. The highest individual pump efficiency was the two-stage pump for the two-lift system. However, the four-stage pump for the single lift showed only a small difference in efficiency—not great enough to support a decision based on efficiency alone.

The three-lift scheme was eliminated because construction of the number of forebay dams and pumping plants in the seismically active region high on the mountain slopes was not considered desirable from an engineering or geological standpoint.

Study of the two-lift and single-lift systems indicated that the single-lift system had many advantages, including simplified operational control. This would reduce the probability of human error in operations and the number of employees required for operation and maintenance. In the final analysis, the single-lift system was selected because of better reliability, increased safety, and lower cost.

These studies were very extensive and are fully described in Bulletin No. 164, "Tehachapi Crossing Design Studies", dated 1968, published by the State of California, Department of Water Resources. The Bulletin is published in six volumes as follows:

Volume I	Comparative Analysis
Volume II	Technical Studies
Volume III	Investigation of High Speed Pumping Practice in Europe and the United States
Volume IV	Program Management
Volumes V and VI	Unnamed. These volumes contain documents substantiating the activities in the preceding volumes

After the single-lift system was selected, the "U"-shaped plant was developed because it was more economical and better suited from the standpoint of local topography, geology, and manifolding requirements of the underground discharge lines. It allowed symmetrical placement of 14 pumps to receive canal flow uniformly and then feed into two discharge lines through relatively simple manifolds. The narrow plant fit into the valley with only moderate excavation on good foundation.

Plans for the single-lift system with a "U"-shaped plant were presented to the Tehachapi Crossing Consulting Board. The Board concurred with the proposed design and, in addition, recommended that hydraulic model studies be made to verify the hydraulic adequacy of the forebay and the intakes regarding equal distribution of water to each pump.

Model studies of the intake conditions were performed at the Hydraulics Laboratory of the Department of Water Science and Engineering at the University of California at Davis. Two undistorted models constructed at scales of 1:18 and 1:48 were tested. Both models consisted of approach channel, transition forebay, pump inlets, and suction elbows of the Pumping Plant. The 1:18 model was used to test the configuration proposed in preliminary designs. The 1:48 model, being smaller and more flexible, was used to test ten alternative transitional configurations.

The proposed preliminary configuration proved to be equal or superior to the ten alternative transitional configurations tested. It was found to be insensitive to minor changes in geometry and flow conditions. The tests indicated that all pumps would function with approximately equal effectiveness, which had been the primary concern of the Board. The preliminary design configuration, with minor modifications, was adopted for final design.

Site Development

Major features of the site development were excavation of the bowl and canal transition. Other features included access roads, two visitor overlooks, and a switchyard. The maximum width of the bowl excavation is about 1,100 feet, and the length, including the canal transition, is about 1,200 feet. The maximum depth of cut is about 190 feet. At the south end (downstream), 1:1 slope cuts were made with 20-foot benches spaced vertically at about 40-foot intervals. The side cuts, also benched, are less steep. Approximately 4,000,000 cubic yards of material was removed from the site and placed in designated spoil areas.

Prior to excavation, static water-level measurements in exploratory drill holes indicated the presence of artesian conditions, and it was predicted that dewatering would be needed during construction; however, only a minor amount of water was encountered.

Plant Structure

The plant was constructed in the shape of a "U" with the wings diverging 7 degrees with the symmetric centerline. The "U" opens to the north. Each wing is divided into five bays: four pump bays, and a service bay at the south end. Between the wings at the south end is the motor-generator bay. It is adjacent to a service bay and part of a pump bay on each side. Each pump bay adjacent to a service bay contains only one pump. The other three bays of each wing were designed to house two pumps each.

Each pump bay is 70 feet (measured along the wing) by 115 feet, with the exception of the pump bays at the upper (north) ends of the "U" which are 94 by 115 feet, each. The additional length of the upper-end bays provides space for stairways, storage space, and valve gallery access hatches. Total depth of the bays, excluding the superstructure, is approximately 100 feet from the top floor at elevation 1,246.5 feet to the plant foundation at elevation 1,147.0 feet.

To minimize the effects of temperature and shrinkage on the structure, the bays are separated by transverse contraction joints below elevation 1,185 feet and by 1-inch expansion joints above that elevation.

The machine hall floor is depressed to elevation 1,210 feet. The top of the main walls at elevation 1,245.75 feet provides direct support for the machine hall bridge crane. The normal water surface in the forebay is at elevation 1,239 feet, which is 29 feet above the machine hall floor. The pump bays in each wing have been sized to provide adequate space for the machine hall, electrical gallery, switchgear gallery, mechanical gallery, and valve gallery.

The motor-generator bay is 123 feet - 4½ inches long by 65 feet wide. The two 35,000-hp motor-generators, used for starting pump motors, are located at elevation 1,210 feet. The visitors area and control room are located in the north half of the motor-generator bay at elevation 1,246.5 feet overlooking the end of the forebay.

The service bays at the south end of each wing are 82 feet - 4½ inches by 109 feet - 1 inch. They contain four floor levels: elevations 1,246.5, 1,229.0, 1,210.0 and 1,192.0 feet. The machine hall floor (elevation 1,210 feet) extends from the pump bays two-thirds of the way into the service bay. Rooms are provided for miscellaneous equipment around three sides of the machine hall at elevations 1,229 and 1,210 feet and over the entire area at elevation 1,192 feet. The rotor erection pier is at elevation 1,192 feet; an access hatch is located overhead in the machine hall floor, and the rotor assembly mandrel soleplates are nearby in the machine hall. The machine hall area, which extends into the service bay, is serviced by a multiple-crane system that includes machine hall gantry cranes and a motor-generator bay gantry crane. This overlapping crane service provides for transfer (double-handling) of heavy equipment to all areas of the plant.

Waterways

Intake Facilities. The forebay consists of a flared transition and a pumping pool enclosed on three sides by the pumping plant structure. Expensive wingwalls were eliminated by flaring the transition. Upstream from the transition, the canal has a trapezoidal shape with side slopes of 2:1 and a 24-foot bottom width. From the beginning of the transition to the plant, the channel flares from a width of 118 feet to approximately 380 feet in a distance of 286 feet. The bottom flares from 24 to 30 feet in a distance of 14 feet, then continues at the 30-foot width. The configuration of the invert is such that the bottom forms a mound in the pumping pool, sloping from its centerline to the pump intakes. Model studies, mentioned previously, indicated that the mound had little or no effect on the hydraulic performance of the pumping pool, and removal of the mound was not required.

Steel trashracks are located at the upstream face of the pump structure. They are followed by gate slots which extend upward to the gate deck at elevation 1,246.5 feet. Structural-steel bulkhead gates can be lowered from the gate deck through these slots to cover the suction tubes and permit their dewatering.

Suction elbows bend at 135 degrees to meet the invert of the forebay; they are steel-lined below the gate slots. A dewatering outlet is provided at the low point of each tube.

Pump Discharge Lines. Major features of the pump discharge conduit system at A.D. Edmonston Pumping Plant include manifolds, underground discharge line tunnels, and a surge tank.

Along with other features of the Tehachapi crossing, this discharge conduit system was discussed at numerous meetings of the Tehachapi Crossing Consulting Board, which worked closely with the Department's staff on conceptual development and design.

Total design pressure head for the discharge conduit system varies from 2,677 feet at the plant to 120 feet inside the surge tank. This design head includes static head, friction losses, and hydraulic transients following simultaneous power failure to all pumps in one wing of the plant. Variations in hydraulic transients throughout the length of the discharge line tunnels cause design head to vary parabolically rather than linearly. Design head at the surge tank depends on the elevation of the hydraulic gradeline in the downstream tunnel system which establishes the water level in the surge tank. This condition is discussed in more detail in Volume II of this bulletin.

Manifolds. Flow from the 14 pumping units is combined by manifolds into two underground discharge line tunnels. All pumps in the east wing of the plant are manifolded to a common discharge header; west wing units are manifolded in the same manner. The east manifold is 244 feet long and the west one is 259 feet. The branch pipe from the most upstream pump enters the end of each manifold while the other six branch pipes enter at 60 degrees from the manifold centerline.

Manifold headers were designed as a series of cone sections that expand from a diameter of 4 feet - 6 inches at upstream ends to 12 feet - 6 inches at outlet ends. This provides nearly constant flow velocities within each header, approximately 18 to 20 feet per second with seven pumps operating (Figure 550).

Complete hydraulic model studies were made on manifold headers by testing the effects of 45- and 60-degree intersections by the branch pipes. These tests measured hydraulic efficiencies, head losses for all pump combinations, and pressure fluctuations around inside crotch girders. The test report recommended 60-degree intersections.

Figure 550. West Manifold Header

Vibrations of manifolds due to pump impulses and effects of flow at the internal reinforcing girders were fully considered in the design, and manifold geometry was adjusted to minimize vibration effects.

Because of the high design head and large diameter, high-strength steel plate, as described in Chapter 1 of this volume, is used for the manifold. This steel is equivalent to ASTM A537, Grade A, although plate thickness exceeds the thickness governed by this specification. All branch pipe shells are $1\frac{1}{2}$ inches thick. In the manifold header, shell plate thickness increases from $1\frac{1}{2}$ to 4 inches at the largest end. Steel plate in the reinforcing girders for the wye branches varies from 2 to 4 inches for outside girders and from 5 to $5\frac{1}{2}$ inches for inside crotch girders.

Geometry of reinforcing girder intersections was determined, to a large extent, by welding requirements. Because of plate thicknesses and obtuse angles of plate intersections, 6-inch steel pins were used at junctions of the two external reinforcing girders with the crotch plate. Pins up to 13 inches in diameter were used at shell and crotch plate sections. These details simplified welding and welds were more resistant to laminar tearing than direct plate-to-plate intersections (Figure 551).

Stress conditions in reinforcing girders and adjacent shell plates were estimated by elastic methods and checked by computerized finite element analysis.

Numerical solutions were then verified by hydrostatic tests, on plastic models and on a prototype. For the plastic models, two wye branches were tested by air pressure using strain gauges attached at significant locations. Prototype testing was made of the largest wye branch on the east manifold when sealed by bulkheads in the fabricating shop. Over 170 strain gauges

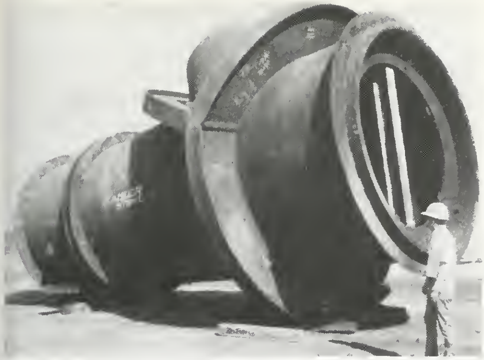

Figure 551. Typical Wye-Branch Intersection

Figure 552. Installing Middle Ring for Sleeve Coupling on a Roll-Out Section

were used to record effects of 1,500 pounds per square inch (psi) test pressure in the full-sized vessel. Stress conditions from the models and prototype compared favorably with the analytical solutions.

Three sleeve couplings were installed on each manifold header to allow for longitudinal expansion and contraction consistent with that provided for the plant structure. The entire manifold was concrete-encased, with the exception of sleeve couplings which were placed in vaults accessible from inside the plant structure.

Prior to concrete placement, completed manifolds were bulkheaded and tested in-place at 1,500 psi. The pipe shell under the sleeve couplings was not cut until after testing and encasement, thus eliminating need for extra supports to resist hydrostatic thrust exerted against the bulkheads. However, holes were drilled through the shell so that the couplings were subjected to the same test pressure as the other manifold components. After testing, pressure was reduced to 800 psi when the manifold was encased in concrete.

A roll-out section with sleeve couplings was installed at the junction of each manifold and downstream discharge pipe (Figure 552). This section is capable of accommodating differential movement between the plant structure and discharge pipe and provides a full-diameter access to the inside of the manifold and discharge pipe. It is rail-mounted for ease of transverse movements, as required. The roll-out section is located in a room accessible both from inside the plant and also by an overhead access hatch located outside the plant at ground level.

Underground Discharge Line Tunnels. Underground discharge line tunnels are considered to be the safest and most reliable method for conveying water from A.D. Edmonston Pumping Plant. Surrounding rock is reasonably strong along the underground alignment so the discharge line tunnels are steel-lined with internal pressure resisted by composite action of the steel liner and the rock mass. Each tunnel is 12 feet - 6 inches in diameter from the manifold to about midpoint of the overall length, where it enlarges to 14 feet in diameter. Total length of each discharge line tunnel is approximately 8,300 feet.

The selected profile provided minimum length and best alignment to meet the basic requirements for excavation and installation of the liner. To facilitate underground work, an adit was constructed at about midpoint of the conduit. The adit also allowed midpoint access into the completed tunnel lines by means of a roll-out section, similar to the one at the manifold.

The specification for steel liner plates was the same as that used in the manifold. Plate thicknesses were required from ½ to 1½ inches. Design stress was 70% of yield stress or approximately 35,000 psi. Liner units were furnished in 40-foot lengths and shop-tested to 90% of yield stress.

A testing program was established to determine deformation modulus of the rock throughout the length of the tunnels because this factor controlled steel-liner thickness. The program included laboratory testing of rock specimens and jacking tests performed in recesses excavated in side walls of the tunnels. At a few tunnel sections with less than minimum strength rock, additional reinforcing was provided around the liner shell by butt-welded steel reinforcing bar hoops placed in the concrete envelope.

Steel tunnel liners also were designed to resist, when dewatered, an external hydrostatic pressure equal to the height of water extending from the tunnel to the ground surface directly above (Figure 553). External stiffener rings constituted the principal reinforcement for these external loads.

Following installation of the steel liner, the space between the tunnel wall and the liner was backfilled with concrete. After placement of backfill, voids in the surrounding rock and backfill were pressure-grouted through pipe fittings welded to the steel liner shell.

Figure 553. Typical Steel Tunnel Liner

Figure 554. Conduits Meeting Under Surge Tank Base and Orifices Into Tank

A two-stage hydrostatic test was made on the completed conduits. Bulkheaded lower reaches of both conduits were tested first because the static pressure had to be higher. Second-stage testing was then applied to the entire conduits. Tests were successful and the conduits were approved for service.

Surge Tank. A 50-foot-diameter, steel, surge tank 68 feet high is installed over the upper end of the discharge conduits. The tank is designed for future extension to a height of 108 feet, required when the plant is operating at full capacity. Under the tank, the two 14-foot-diameter discharge conduits converge into one 23½-foot pipe which carries the water into Tehachapi Tunnel No. 1, and then through subsequent tunnels downstream (Figure 554). The surge tank is directly connected to each 14-foot-diameter conduit by a 14-foot orifice.

The tank provides a free water surface in the system, controls transient pressures by providing a relief point for pressure waves, and prevents water column separation in the vertical conduit bend immediately upstream of the tank in the event of a sudden loss of pumping capability at the plant.

A roll-out section is provided in each 14-foot pipe at the base of the surge tank, and a lift-out section is installed for access into the 23½-foot pipe.

Backflow from the downstream tunnel system in the Tehachapi Division (see Volume II of this bulletin) can be prevented by two 168-inch butterfly valves installed in each conduit on the upstream side of the tank. With these valves, either discharge conduit can be drained without interruption of pumping and both conduits can be drained without dewatering the downstream tunnels. A 5-foot relief pipe exits into the tank to bypass any pumping flow if a pump should be accidentally started with one of the butterfly valves closed.

Mechanical Features

A. D. Edmonston Pumping Plant was designed to lift 4,410 cfs 1,926 feet in a single lift from where it flows by gravity across the Tehachapi Mountains.

Prior to selection of the single-lift scheme, three possible lift plans were selected for complete engineering analysis: a single-lift scheme of 2,000 feet, a two-lift scheme of 1,000 feet each, and a three-lift scheme of about 670 feet each.

Because of the lack of experience in the United States with large high-head pumping plants, the Department of Water Resources, as part of its engineering program for the Tehachapi crossing, entered into a contract with Daniel, Mann, Johnson, and Mendenhall of Los Angeles, in association with Motor-Colombus of Baden, Switzerland, for a research and pump model testing program. This program was to determine and analyze the feasibility, reliability, and efficiency factors for each lift system. Major emphasis was placed on a model analysis of a single-stage model to serve in a three-lift system, a two-stage model to serve in a two-lift system, and a four-stage model to serve in a single-lift system. The two-stage and four-stage pump models were built and tested by European firms with long experience in high-head pump design and manufacture. A single-stage pump model was built and tested in the United States.

The models manufactured for the pump study were tested for:

1. Head, capacity, efficiency, and net positive suction head
2. Normal and abnormal operating conditions (three-quadrant study)
3. Pressure fluctuations
4. Inlet velocity distribution
5. Axial and radial thrust forces

These tests provided the basic information necessary for designing A. D. Edmonston Pumping Plant and analyzing its operation.

The pump performance test was to determine if the manufacturer met the head-capacity and efficiency guarantee of the contract. The award of contract and the guaranteed efficiency were determined as follows. The procurement of these pumps was through the bidding process with award of contract to the lowest evaluated responsible bidder. The requirements were that each bidder submit a model of the pump to a preselected independent laboratory for determination of pump performance, including efficiency. These tests were performed at the National Engineering Laboratory (NEL), East Kilbride, Glasgow, Scotland, under extreme secrecy and security to prevent the competitors knowing each other's performance results.

A "dead band" allowance of 0.2% was applied to three prequalified bidders' comparative prototype efficiencies determined by the model tests. This allowed for scatter and inaccuracy in the comparative model testing. Efficiencies in the "dead band" were considered equal for purposes of the evaluation and each efficiency more than 0.2% below the highest comparative prototype efficiency was evaluated on its departure from the "dead band". This procedure is:

Bidding Procedure

Efficiencies, as a percentage	Bidder A	Bidder B	Bidder C
Comparative prototype efficiency (%)	91.4	91.7	91.9
Departure from highest comparative prototype efficiency (%)	0.5	0.2	0
Departure from "dead band" or "evaluated difference" (%)	0.3	0	0

For bid evaluation purposes, $210,000 was added to the bidder's total price for each 0.1% of "evaluated difference." For example, $630,000 would be added to the total price of Bidder A for comparison with the other bidders.

The efficiencies determined at NEL projected to the prototype were 92.2% for the BLH/Voith pumps and 92.4% for the AC/Sulzer pumps. Field efficiency tests were conducted recently on the BLH/Voith pump. Inaccuracies of 1.5% in field testing were allowed in the specifications, resulting in a minimum field efficiency of 90.7%. A 91.4% efficiency was achieved, not taking into account leakage water through the shaft seals and balancing labyrinth. Consideration of the leakage water would reduce the efficiency to approx 91.1%, which is substantially above the minimum.

General

The ultimate mechanical installation at A. D. Edmonston Pumping Plant will include 14 pumps and discharge valves, 8 cranes, and auxiliary equipment.

Chapter I of this volume contains information on the mechanical equipment for this plant common to other plants. Information and descriptions unique to this plant are included in the following:

Equipment Ratings

Pumps

Manufacturer:	Pumps Nos. W2, W4, W6, and W8	Allis-Chalmers Manufacturing Company
	Pumps Nos. E1, E3, E5, E7, E9, E11, and E13	Baldwin-Lima-Hamilton
Hydraulic Design:	Units Nos. W2, W4, W6, and W8	Sulzer Brothers Limited, Winterthur, Switzerland
	Units Nos. E1, E3, E5, E7, E9, E11, and E13	J. M. Voith Company Heidenheim, Germany
Efficiency:	Units Nos. W2, W4, W6, and W8	92.4%
	Units Nos. E1, E3, E5, E7, E9, E11, and E13	92.2%

'W' refers to west-wing and 'E' refers to the east-wing units

Type:	Vertical-shaft, four-stage, centrifugal	
	Discharge, each:	315 cfs
	Total Head:	1,970 feet
	Speed:	600 rpm
	Minimum Submergence:	71 feet

Pump Discharge Valves

Manufacturer: Allis-Chalmers Manufacturing Company
Type: 48-inch-diameter, spherical, with movable seats

Surge Tank Valves

Manufacturer: Willamette Iron and Steel Company
Type: 168-inch, metal-seated, butterfly

Cranes

Manufacturer: Crane Hoist Engineering and Manufacturing Company
Type: 105-ton, electric, cab-operated, indoor, overhead, traveling, bridge
Manufacturer: Fulton Shipyard
Type: 10-ton, electric, cab-operated, outdoor, traveling, gantry
Manufacturer: M. P. McCaffrey, Inc.
Type: 65-ton, rubber-tired, outdoor, gantry

Eleven pump units are presently (1974) installed and operating. The remaining three units are scheduled for operation in 1983.

Pumps

The pumps are the vertical-shaft, four-stage, centrifugal type directly connected to vertical-shaft synchronous, motors. All pumps rotate counterclockwise as viewed from the motor end (Figures 555, 556, and 557).

Each pump unit includes an inlet transition, suction bend, casing, discharge spiral, extension pipe, compensation joint, upper and lower self-lubricating bearings, upper and lower shaft seals, removable shaft coupling, hydraulic downthrust control labyrinth, renewable wearing rings, and stainless-steel impellers (Figures 558, 559, 560, and 561).

The impellers are one-piece, enclosed, single-suction, cast from 13% chrome steel conforming to ASTM Designation A296, Grade CA-15, heat-treated to a hardness of 248 to 302 BHN.

The pumps are entirely exposed and designed to be moved out of their normal position on horizontal rails to crane service areas for maintenance or repair (Figure 562). Compensation joints on the pump extensions relieve the hydraulic thrust from the pump mountings. The compensation joints located between the pump extension pipes and the discharge valves also function as expansion joints (Figures 563 and 564). The pumps are started watered as discussed later in this chapter.

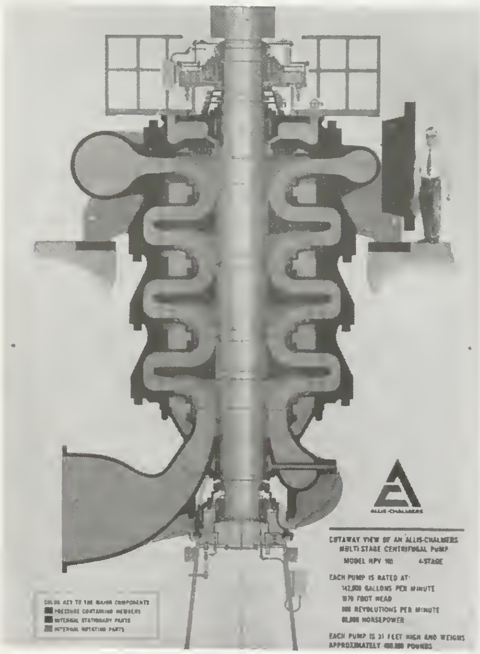

Figure 555. Cutaway View of West Wing Pump

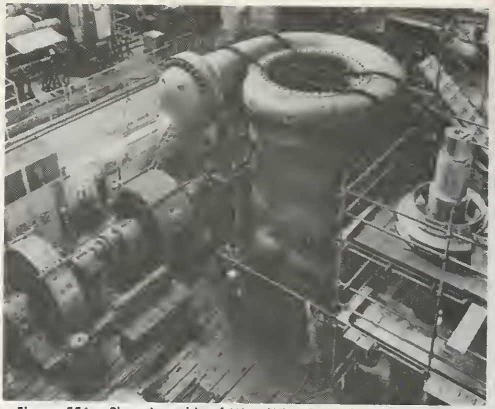

Figure 556. Shop Assembly of West Wing Pump for Hydrostatic Test

Figure 557. Suction Piping—East Wing Pump

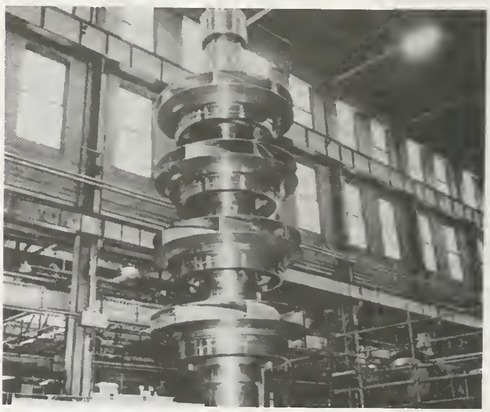

Figure 558. Pump Shaft Assembly

Figure 559. Partial Assembly of West Wing Pump

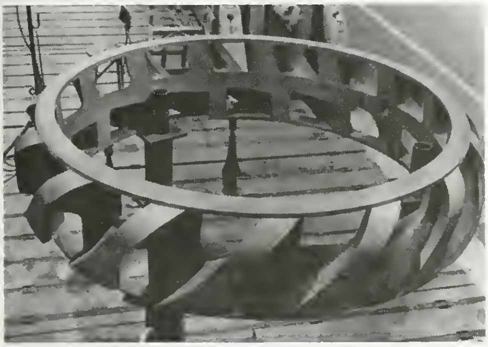

Figure 560. Crossover Piece Between Stages

Figure 561. Inverted View of Fixed Part of Balancing Labyrinth—West Wing Pump

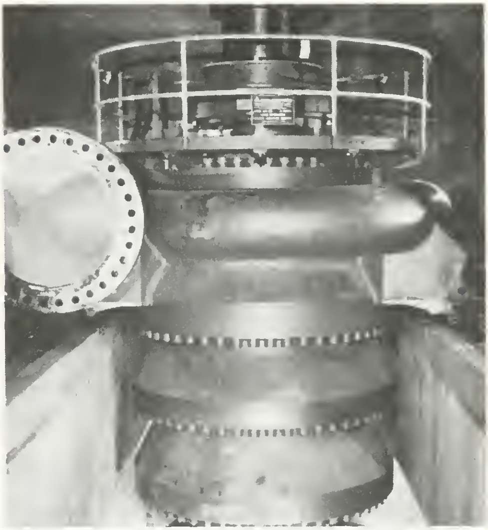

Figure 562. Completing Assembly of West Wing Pump

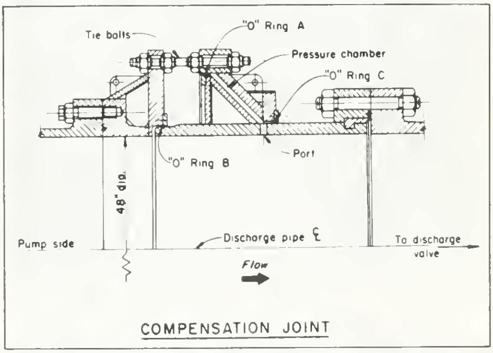

Figure 563. Cross Section Through Compensation Joint

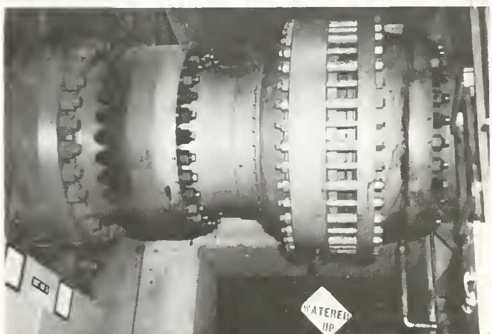

Figure 564. Compensation Joint

35—87370

Some of the major problems which developed during the initial operating period are:

1. Excessive hydraulic downthrust—The total downthrust on the "W" (west side) units exceeded the thrust bearing rating by 27%. The manufacturer was able to lower the downthrust to the bearing rating by modifying the pump balancing labyrinth.

2. Coating failure—Pump Unit No. W2 had epoxy coating on its interior ferrous surfaces which did not adhere to the pump surfaces and peeled off requiring complete disassembly to remove the epoxy. The surfaces were subsequently recoated with red lead.

3. Labyrinth failure—The balancing labyrinth on Unit No. E13 seized soon after being put into operation. The failure was apparently due to the use of cap screws that were shorter than specified and of the wrong material.

4. Cavitation damage—The first-stage impellers of the "W" pumps suffered severe cavitation damage almost immediately after each pump went into service. The manufacturer tried to remedy this by injecting air into the suction and changing the contours of the first-stage impeller vanes but was not successful. Subsequent model tests of the suction bend revealed that a vortex formed near the bottom of the bend. The vortex went upward and entered the impeller eye near the outer shroud, striking each vane as the unit rotated. Various changes in configuration were made in an attempt to eliminate the vortex. The optimum solution, and the one selected, consisted of adding boundary layer fences on the bottom of the suction bend and a bell-like suction device in the throat of the bend. This modification reduced the noise level considerably; however, without air injection, there is still distinct crackling emanating from the suction. The introduction of air into the suction piece causes the crackling to entirely disappear. At this time, there is insufficient operating time on the pumps to determine if the modifications were effective in reducing the cavitation damage sufficiently to meet the specification's cavitation requirements.

Pump Discharge Valves

The pumps in each wing are manifolded into one discharge line approximately 8,700 feet long. Because of the manifolding, it was necessary to install a valve on each pump discharge to act as a pump check to simplify pump operation and maintain a full discharge line (Figures 565, 566, and 567).

The pump discharge valves have movable metal seats on both the upstream and downstream sides of

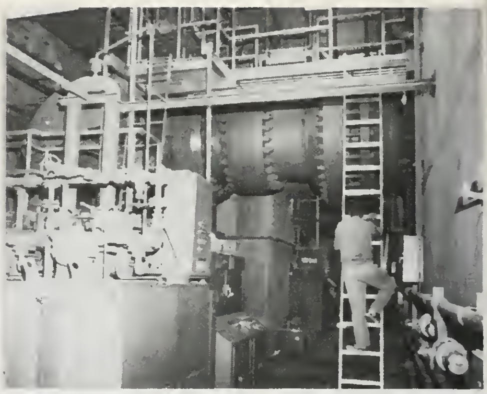

Figure 565. Discharge Valve and Compensation Joint Gallery

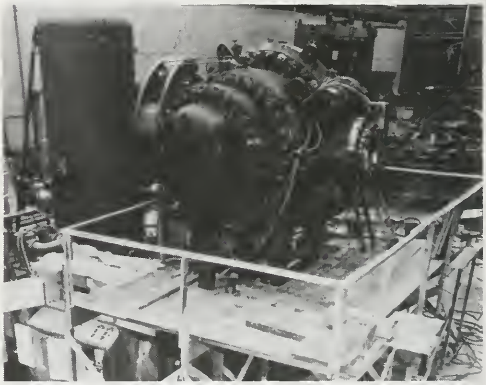

Figure 566. Shop Hydrostatic Test of Valve

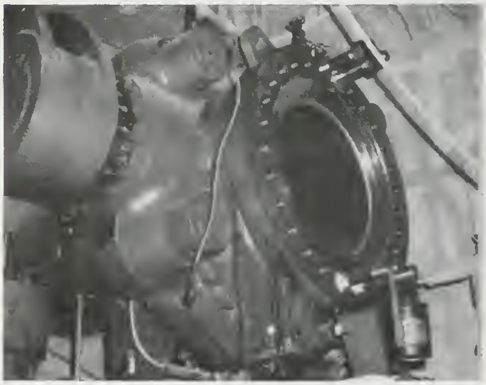

Figure 567. Partially Assembled Valve

the valve. The main parts of the valve consist of a flanged body and a sphere or plug with a full opening the same size as the pump discharge (Figures 568, 569, and 570). The plug can be rotated 90 degrees inside the valve body by a hydraulic cylinder attached to a lever arm connected to the trunnion. The movable seats are annular rings that butt against the fixed seats on the plug for sealing. The movable seats are actuated by oil pressure in an annular cavity on each side of the seat ring. The "O" rings seal these cavities from the water in the discharge lines. The seats are fully retracted during plug rotation. The plug has trunnions integrally cast with a removable lever arm attached to a hydraulic cylinder for turning the sphere. The hydraulic cylinder and the movable seats are operated by hydraulic oil pressure created by compressed air in an air-over-oil accumulator. These valves will close automatically upon power failure, utilizing the energy stored in the accumulator. The downstream seat normally remains open with the upstream seat providing operating service. The intent of this design was to have the equivalent of two valves in series, one operating as a shutoff valve and the other as a back-up valve. If the operating seat needs repair or replacement, the downstream seat will be activated for shutoff, allowing the other pumps in the wing to continue operation.

Four major problem areas which developed during the initial operation of these valves were:

1. Malfunction or leaking of the seat "O" rings.
2. The cap screws attaching the stationary seat rings to the valve plug were loose.
3. Slamming of the float-operated check valve located in the hydraulic system accumulator.
4. Control system failures.

In May 1972, during preparation for the initial start of Unit No. E5, after manually opening the downstream seat, it was noted that water was contaminating the oil system past the "O" rings. Operators were unable to close the downstream seat until an external pressure source was used causing it to finally close. A review of this condition concluded that since the water pressure in the discharge line was approximately 850 psi and the seat operating pressure was approximately 500 psi, a serious operational problem exists if defective "O" rings were present. The valve manufacturer was consulted and finally recommended that a high-pressure (1,000-psi), separate, oil accumulator system be installed to actuate the seats of each valve. The 500 psi was retained as a back-up for the 1,000-psi seat system and remained the power source for movement of the valve plug.

An opportunity to inspect the "O" rings presented itself in August 1972, when the eastside discharge line was dewatered to inspect the valve seats. This inspection confirmed the assumption that the rings were defective by evidence of large cuts and gouges in the rings. Also, it was found that the rings were too long, which may have contributed to the damage.

Figure 568. Plug Casting Removed From Mold

Figure 569. Plug Casting—Upgraded and Heat-Treated

Figure 570. Completed Plug Casting

The second problem became apparent during the investigation of the "O" rings when a 1-inch cap screw was discharged from the silt blowoff line on the valve on Unit No. E1. The only possible location from which this cap screw could have come was the hold-down bolts on the plug or fixed seat. All the spherical valves were inspected, and loose cap screws were found on all valves. Severe damage occurred to both the movable and fixed seat on the valve on Unit No. E1. This defect in the valves was corrected by tightening and spot welding all the cap screws.

The third problem occurred in the accumulator of the 500-psi hydraulic system. The inlet-outlet pipe on this pressure tank has a 6-inch float-operated valve that slammed closed violently on initial operation of the discharge valve after the system had remained idle for several weeks. (The purpose of the float-operated valve is to prevent air from entering the hydraulic system.) This unacceptable operation could result in collapsing of the float and damage to the valve linkage, which could leave the entire hydraulic system inoperable. It was theorized that the hydraulic oil in the pipe on the vented side of the cylinder was draining back to the oil sump, leaving a void in the pipe. During initial operation of the hydraulic system, the void did not create sufficient resistance to the oil supplied from the accumulator, allowing high-velocity oil to flow around the float causing the valve to slam. The solution to the problem was installation of a loop in the pipe to prevent drainage of the hydraulic oil.

The fourth problem occurred in operation of the control equipment. Failures had occurred on the seat-limit switches, float switches, and cam-operated limit switches. Poor electrical contacts were found on the electric clutches in the sequencing circuit, and the push-pull cable used to transmit valve plug position to the cam stop had failed. The valve sequencer also had been affected by spray painting of the moving sequencer mechanism.

Each valve failure was and will continue to be investigated to determine the cause of the malfunction and the necessary corrective action taken.

Equipment Handling—Cranes

There are five identical, 105-ton, electric, cab-operated, indoor, overhead, bridge cranes in the plant. One crane operates in the service and motor-generator bays, and two cranes on common tracks serve each plant wing. The bridge cranes are used for assembly and maintenance of the main pumps and motors, motor-generator sets, and plant auxiliary equipment (Figure 571).

Two identical, 10-ton, outdoor, gantry cranes on the forebay decks handle the pump intake bulkhead gates and trashracks (Figure 572). A 65-ton, rubber-tired, gantry crane integrally powered is used for handling the pump discharge valves (Figures 573, 574, and 575).

The rated capacities, and speeds of the bridge cranes are:

Rated capacity, tons	105
Number of trolleys	1
Rated capacity of main hoist, tons	105
Rated capacity of auxiliary hoist, tons	25
Maximum lift, main hoist, feet—inches	84′—6″
Maximum lift, auxiliary hoist, feet—inches	91′—6″
Span, feet	54
Hook speeds—feet per minute (fpm)	
Main (variable speed)	3.2
Aux. (variable speed)	15.7
Bridge speed—fpm (5 step) variable	82
Trolley speed—fpm (5 step) variable	32.4

Figure 571. 105-Ton Bridge Crane

Figure 572. 10-Ton Gantry Crane

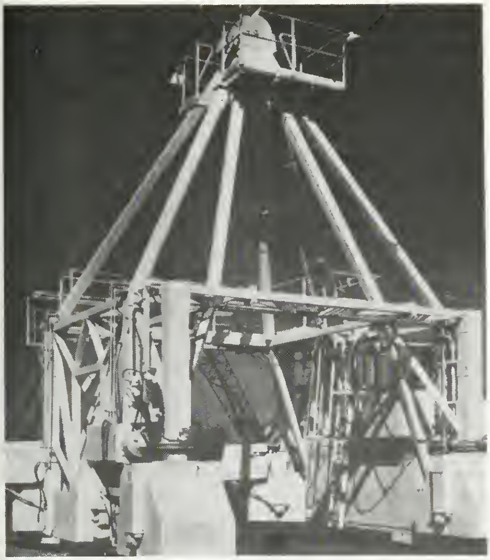

Figure 573. 65-Ton Rubber-Tired Gantry Crane

Figure 574. Closeup View of 65-Ton Gantry Crane

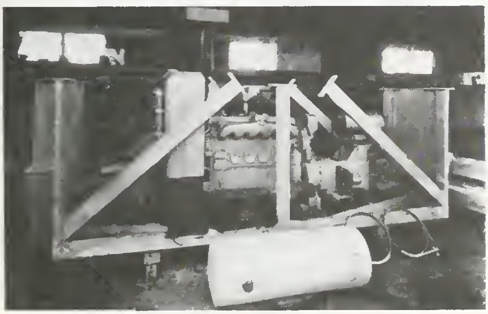

Figure 575. Partial Assembly of Gantry Crane Power Plant

Brakes are provided for hook, trolley, and crane travel. They include both the electric and hydraulic shoe type, with shunt coil and manual release lever.

The rated capacity and speeds of the 10-ton gantry cranes are:

Rated capacity, tons	10
Number of trolleys	1
Span, feet—inches	18′—3″
Hoist speed with maximum working load, fpm	4 to 5
Gantry travel speed with maximum working load, fpm	30 to 40
Trolley travel speed with maximum working load, fpm	3 to 5
Maximum lift, feet—inches	82′—6″

The rated capacity and speeds of the 65-ton gantry crane are:

Rated capacity, tons	65
Hoist speed with maximum working load, fpm (variable speed)	0 to 10
Gantry travel speed with maximum working load, fpm	30 to 50
Gantry travel speed with no load, fpm	150 to 400
Maximum lift, feet	100
Span, feet	18

The rubber-tired gantry crane has four wheels with two 16.00 × 25, 24-ply-rating, rubber tires on each wheel. Two wheels are used for both driving and steering. The remaining two wheels are supported on hydraulic cylinders which balance the load between them so that all four wheels can take the load without deflecting the frame.

A diesel engine-driven hydraulic power unit is used for the main propulsion and hoist drives. The hydraulic system also powers the steering and jacking arrangements. The hydraulic jacks raise the crane off the rubber-tired wheels during storage and for traversing the load from side to side. The crane is controlled from the operator's platform mounted on the crane or from a remote control panel.

Filling and Dewatering of Discharge Lines

The two discharge lines are approximately 8,700 feet long and each has a volume of over 16 million gallons. There will be times when it is necessary to drain the discharge lines for inspection and maintenance. Separate pumps were installed to fill the discharge lines (Figure 576). These fill pumps are required only when both discharge lines are empty. With one discharge line filled, the other line can be filled through a valved cross connection at the crest of the discharge lines. Since the lines rise approximately 1,900 feet in elevation, the potential energy of the stored water is substantial. Under 1,900 feet of head, the spouting velocity is 350 feet per second. In order to drain the lines safely, energy-dissipating valves

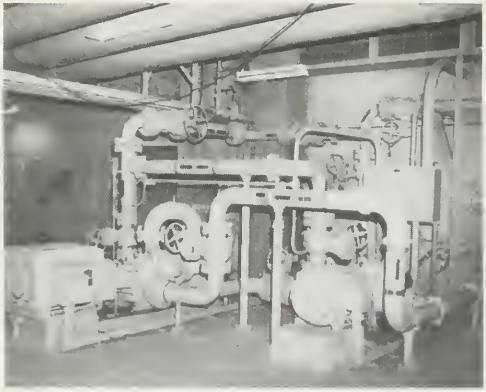

Figure 576. Discharge Line Fill Pumps

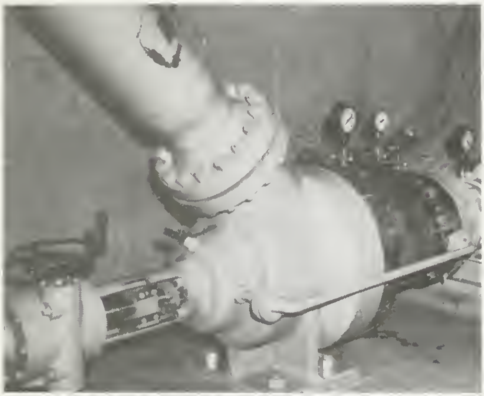

Figure 577. Energy-Dissipating Valve

were provided (Figure 577). The valves are a three-stage poppet type with the poppets mounted on a common shaft. Each stage was designed to reduce the upstream pressure by 50% with the last stage discharging into the forebay. Fifteen hours are required to lower the water to forebay elevation. To drain the remaining portion of the discharge line, including the manifold, the flow from the pressure-reducing valve is diverted to the plant drainage system and pumped into the forebay.

Surge Tank Valves

A butterfly valve was installed in both the east and west discharge lines upstream of the surge tank. The valves are used for shutoff service to isolate the discharge lines for inspection and maintenance. The valves are 168 inches in diameter and weigh approximately 109,000 pounds each, including cylinder and downstream and upstream nipples. There are two metal seat rings with the body ring being externally adjustable. The valves have horizontal discs, stub shafts, and a latch to hold them in the fully open position (Figures 578 and 579).

A hydraulic cylinder rotates the disc 90 degrees from the fully closed position to the fully open position. The valve body was designed for a working pressure of 65 pounds per square inch gauge (psig), and the valve disc was designed for a full 65-psig differential pressure across the disc.

The valve operator is the clevis or trunnion-mounted type and is vertically supported at the floor of the valve vault. The operating mechanism is composed of an operating cylinder, piston, piston rod, rod pivot, connecting pin, locking device, operating lever, swivel joint, and mounting bracket.

The cylinder is double-acting, with the control system designed to simultaneously vent one side of the cylinder to the oil sump tank and allow oil to enter the other side under high pressure from the accumulator

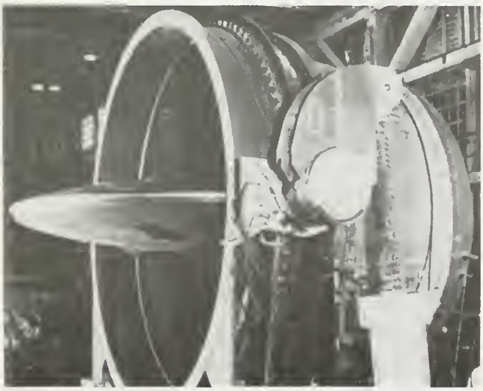

Figure 578. Shop Testing of 168-Inch Butterfly Valve

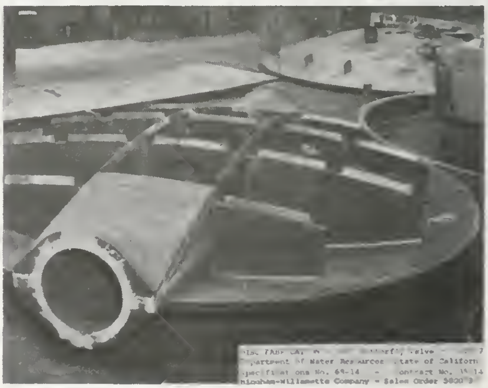

Figure 579. Fabrication of Disc for 168-Inch Butterfly Valve

bank. The rate of valve movement is controlled by adjusting the pressure on the discharge side of the cylinder by means of flow control valves.

The valve is normally held in the open or closed position by oil pressure in the operating cylinder. A manually operated mechanical lock (two pins) on the rod pin of each cylinder locks the valve in the closed position for maintenance. The operator and associated hydraulic system are designed to provide a safe smooth opening with a pressure differential of 25 psig across the disc.

The hydraulic systems include the following equipment: hydraulic power unit; accumulator system; emergency close system; cylinder lock system; and the necessary piping, wiring, and instruments. The fluid power supply consists of a fluid reservoir complete with filler breather, sump heater, low-level switch, liquid-level gauge, clean-out covers, hydraulic pump motor, hydraulic pump, suction filter, relief valve, check valve, pressure filter, and shutoff valve. A valve control panel on the end of the fluid power supply consists of hydraulic control valves, pressure switches, pressure gauges, suction gauge, and shutoff and drain valves.

The accumulator system consists of the accumulator rack with 13 bladder-type accumulators, a nitrogen pressure vessel, and nitrogen bottles with regulators. The emergency close system is used to close the butterfly valve if electrical or hydraulic power fails. The system consists of a nitrogen bottle with regulator, hose, and a quick-connecting coupling.

A lock system holds the butterfly valve in the open position without hydraulic pressure supplied to the operating cylinder. The system consists of a single-acting hydraulic cylinder controlled by a two-position, cam-actuated, directional valve. The opening of the 168-inch butterfly valve is by local operation only. The closing of the valve is either by remote control from the plant or by local operation.

Electrical Features

General

The electrical installation includes a 230-kV switchyard, power transformers, motors, starting motor-generator sets, switchgear, bus, and auxiliary systems for station service, communication, and protection of equipment and personnel.

Chapter I of this volume contains information on the electrical equipment and systems for this plant which also are common to other major plants in the State Water Project.

Description of Equipment and Systems

The 230-kV switchyard receives power over a single-circuit transmission line with two bundled conductors, 1,590 MCM, ACSR per phase. It was designed for the main-and-transfer bus arrangement. Six bays switch and protect the transmission line, four load lines to the pumping plant, and one transfer bay for connecting the two buses. One circuit breaker in each bay interrupts the transmission line or load lines in event of faults in the plant or on the line (Figure 580). Breakers also are used in maintenance of the lines and equipment and for normal switching operations. The breaker in the transfer bay is utilized as a substitute breaker for any one of the other five opened for inspection or maintenance. The transfer breaker protects the transmission or load lines during that period. A disconnect switch is on each side of each of the circuit breakers for opening during maintenance of the breaker.

Each of the four 230-kV load lines to the plant is connected to two power transformers through a disconnect switch, which will allow any transformer to be isolated from the line. Lightning arresters were installed at the transmission line connection to the switchyard and at each transformer.

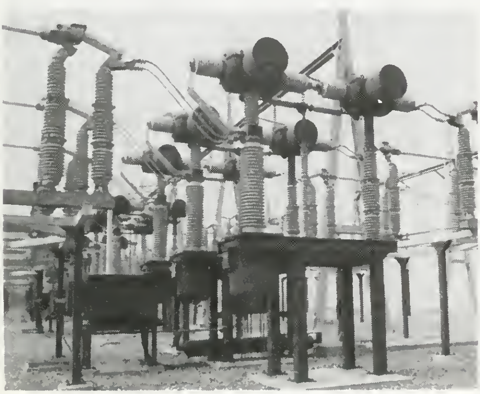

Figure 580. 230-kV Air-Blast Circuit Breaker

Figure 581. 128-MVA Transformers

Eight power transformers ultimately will be installed at the plant, four on the discharge side of each wing (Figure 581). Seven transformers were installed initially. Voltage is reduced from 230 kV to 14.4 kV for the pump motors and station service and to 7.2 kV for the motor-generator sets. Two pump motors are connected to each transformer except for two transformers where each supplies one motor, one motor-generator set, and the station service load.

The 14.4-kV system starts at the power transformers and extends to the pump motors and station service transformers. Circuit breakers were installed in each feeder. The breakers interrupt the circuit to a motor or station service transformer in the event of abnormal conditions or are for normal switching operations.

The 7.2-kV system originates at two of the power transformers for supply to the motor-generator sets. Breakers installed in each feeder protect and operate the loads, as required.

The pump motors drive the main pumps and are started normally by means of the motor-generator set or may be started full-voltage, across-the-line, under emergency conditions. Motors are wye-connected with the high-voltage winding of a distribution transformer connected in series with the grounded neutral. A resistor and relays are connected in the low-voltage winding. The transformer-resistor combination limits ground fault currents and also detects abnormal ground currents for tripping the motor circuit breaker. Surge equipment, consisting of lightning arresters and capacitors, is in the line side of each motor to protect it from transient overvoltages caused by lightning or switching surges.

The station service system has two transformers to supply either end of a 480-volt substation (Figures 582 and 583). Transformers reduce voltage from 14.4 kV to 480 volts and are connected to the secondary breakers with high-capacity 480-volt bus. Connected to the secondary bus are 480-volt feeder breakers for distribution of power to various motor control centers, power distribution centers, and lighting distribution centers, located throughout the plant.

Switchboards house protective relaying, instruments, meters, annunciators, and the local control panel. These boards are supplied for each pumping unit (Figure 584).

Revenue metering equipment was installed in the switchyard. The equipment is located in the transmission line bay and measures total energy supplied at 230 kV.

The plant and pumping units normally will be controlled from the control room. A computer control system in the control room controls, monitors, logs data, annunciates, and displays all functions of the plant and switchyard for operation of the pumping units. In addition to operating the plant from the control room, equipment was installed which permits operation of each unit in the local mode at its switchboard (Figure 585). A panel on each switchboard, with control devices and indicating lights, selectively starts certain equipment until the full starting cycle is complete. Each auxiliary piece of equipment also may be started from motor control centers and distribution centers; however, this would be done only during initial start-up, after major maintenance, or to accomplish a limited test.

Figure 582. 3.0/4.0-MVA Station Service Transformer

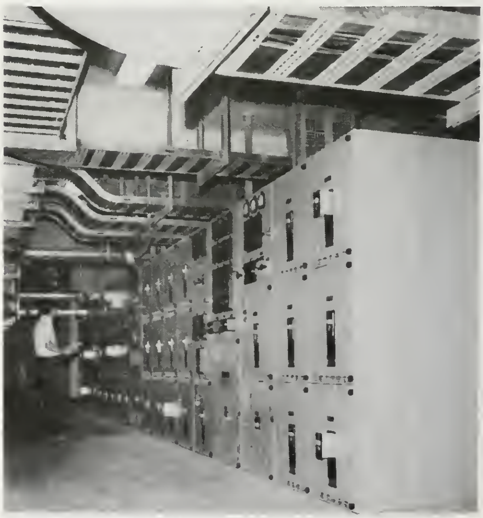

Figure 583. 480-Volt Station Service Substation

The San Joaquin Area Control Center and the Sacramento Project Operation Control Center connect to the plant control computer in the control room. A description and discussion of these control systems are included in Volume V of this bulletin.

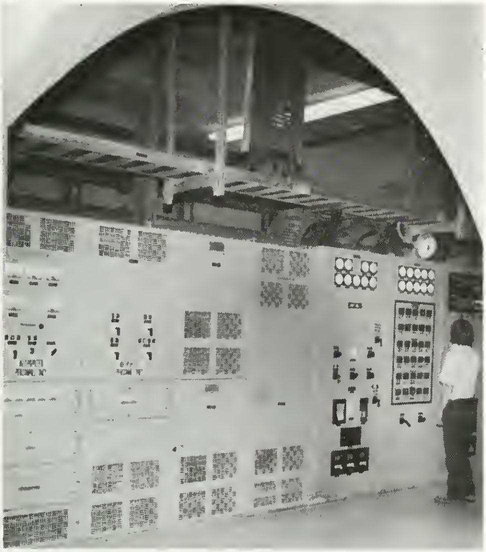

Figure 584. Unit Control Board

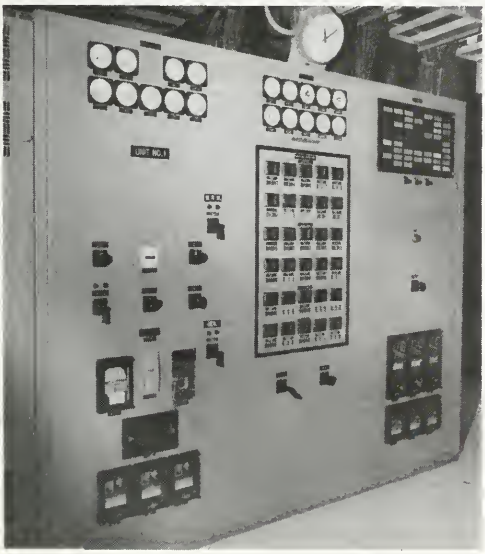

Figure 585. Closeup of Unit Control Board

Equipment Ratings

Motors

Manufacturer: Westinghouse Electric Corporation
Type: Vertical-shaft, synchronous
Horsepower: 80,000
Speed: 600 rpm
Power factor: 95%
Volts: 14,400

Motor-Generator Sets

Motor

Manufacturer: Westinghouse Electric Corporation
Type: Horizontal-shaft, wound-rotor
Horsepower: 35,000
Speed: 720 rpm
Primary volts: 7,200

Generator

Manufacturer: Westinghouse Electric Corporation
Type: Horizontal-shaft, synchronous
Capacity: 20,000 kVA
Speed: 600 rpm
Power factor: 95%
Volts: 14,400

Power Transformers

Transformers Nos. 1 and 2

Manufacturer: Westinghouse Electric Corporation
Type: OA, three winding
Volts: 230-kV primary winding, wye
14.4-kV secondary winding, delta
7.2-kV secondary winding, delta
kVA: 78,000, primary 230-kV winding
67,000, secondary 14.4-kV winding
30,000, secondary 7.2-kV winding
Taps: In the primary winding, 2½ and 5% above and below rated voltage
Connection: Grounded-Wye—Delta

Transformers Nos. 3 through 7

Manufacturer: Westinghouse Electric Corporation
Type: OA, two winding
Volts: 230-14.4-kV
kVA: 128,000
Taps: In the primary winding, 2½ and 5% above and below rated voltage

Station Service

Number of transformers: 2
Volts: 14,400—480Y/277
Phase: 3
kVA: 3,000/4,000
Type: AA/FA
Emergency engine-generator: 300 kW, 480 volts, 3 phase, 60 Hz

Motor Starting Method

Starting of the 80,000-hp 600-rpm motors required careful evaluation. The method selected will be discussed first, followed by alternative methods considered with reasons for their rejection. The multistage pumps are started with water in the pump casing, thus requiring the motors to develop high-starting and pull-in torques. Daily starts for off-peak pumping impose a severe starting duty.

The starting method selected utilizes a wound-rotor motor driving a synchronous generator (Figure 586). With the motor-generator (M-G) set spinning freely (disconnected from the utility line) and slowing down, the pump motor to be started is electrically connected to the synchronous generator. The result is to accelerate the pump motor and decelerate the M-G set until their speeds are equal. At this time, excitation is applied to the pump motor and the generator from a separate excitation source to synchronize the two machines at a reduced frequency. The wound-rotor motor of the M-G set is then accelerated, thereby increasing speed and frequency of the generator and pump motor. When line frequency is reached (60 Hz), the pump motor is synchronized to the utility power source and the excitation system switched from the separate to a direct-connected system. The generator is separated from the pump motor and the wound-rotor motor is deenergized.

Two motor-generator sets were installed. Normally, one set is used on half of the plant and the other set starts motors in the other half. If one M-G set is not available, the starting bus connections may be switched so the other set can start all motors in the plant. The two independent, separate, excitation systems can be similarly employed (Figure 587). The allowable temperature rise for the M-G sets was specified in the procurement specification. This allowed the manufacturer to establish the horsepower rating. The duty cycle of each M-G set was established as two consecutive, complete, plant starts of 14 pumping units with six minutes between successive motor starts and a one-hour interval between the two plant starts.

Use of a M-G set for starting pump motors results in the most favorable conditions for the pump motor. Temperature in amortisseur windings and shock to stator winding are reduced to a minimum. This installation should result in maximum motor life without rewinding. No objectionable voltage dips are involved on the utility transmission line.

Starting with reduced frequency rather than zero frequency was selected because of uncertainty regarding the ability of the M-G set to start at a slow enough speed. If the M-G set started too rapidly, the pump motor could not break away and accelerate at the same rate. The same result could occur if the pump motor and generator happened to stop at an unfavorable, relative, electrical position. This would allow the M-G set to commence rotation ahead of the pump motor and reach too high a speed before the electrical positions coincided.

Starting with reduced frequency also results in a minimum starting inrush for the wound-rotor motor. This was necessary to meet restrictions set by the utility company. This starting method was better for the application in spite of the additional capital and maintenance costs caused by the additional equipment, which includes the M-G sets, speed control system, and separate excitation system.

In addition to being started with the M-G sets at reduced frequency, the motors also are capable of full-voltage starting as an induction motor. Full-voltage starting is to be used only when both M-G sets are inoperable.

Figure 586. Starting Motor-Generator Set

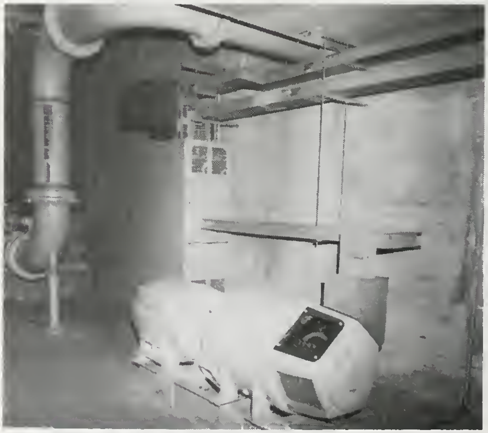

Figure 587. Starting Excitation Motor-Generator Set

Starting Sequence With Motor-Generator Set

The following sequential description for starting a pump motor with a motor-generator set includes only operation of the main equipment.

1. Close the motor-operated disconnect switch between the pump motor and the starting bus (Figure 588).
2. Close the wound-rotor motor breaker.
3. Open the wound-rotor motor breaker when the speed reaches 420 rpm.
4. Close the generator breaker.
5. Close the generator field breaker to apply excitation from the separate excitation system. The pump motor and the generator are now connected together electrically. The pump motor is accelerating and the M-G set is decelerating.

Figure 588. Iso-Phase Bus Motor-Operated Disconnects

Figure 589. 80,000-Horsepower Motor Exciter

6. The starting excitation field breaker for the pump motor will close automatically, applying excitation from the separate system when the slip frequency is 2.5% or less.
7. Close the wound-rotor motor breaker after the generator and pump motor have synchronized.
8. The liquid rheostat will decrease resistance, causing the M-G set and pump motor to accelerate.
9. The pump motor running breaker will close when the bus voltage is in phase and the frequency is matched to the incoming line.
10. Close the running excitation field breaker to apply excitation to the pump motor from its direct-connected exciter (Figure 589).
11. The starting field breaker for the pump motor will open simultaneously with the closing of the running field breaker.
12. Open the generator breaker.
13. Open the wound-rotor motor breaker.
14. Open the generator field breaker.
15. Open the starting bus motor operated disconnect switch.

The pump motor is now synchronized with the normal power supply and ready to pump with the opening of the discharge valve. The M-G set is either available for starting another pumping unit or is shut down.

Alternative Motor Starting Methods

Various methods considered for starting the motors are briefly discussed for the following methods:

1. Full-voltage starting
2. Reactor starting
3. Induction frequency changer starting set
4. Capacitor starting
5. Hydraulic turbine and generator starting
6. Reversible pump-turbine starting

Full-Voltage Starting. The motor is started as an induction motor by closing directly across the line. After approaching synchronous speed, field excitation is applied and the motor synchronized. Direct-connected exciters are utilized for each motor. This method requires minimum accessory equipment, resulting in minimum first cost and lowest maintenance for the plant equipment.

The disadvantages with this method of starting are caused by the high inrush current. Inrush was estimated to be 300 to 400% of rated current. Actual value of inrush measured during testing was 408% of normal. Maximum temperature in amortisseur windings and maximum stress on stator coils would be experienced during starting. Since comparable motors of the same rating and starting duty had not been manufactured, it was necessary to project design data from other motors. This resulted in some disagreement among manufacturers as to whether these motors could be built and operated with across-the-line starting without excessive maintenance.

The high-voltage drop on the 230-kV system would not be acceptable to the utility company if any of the motors were to be started daily. It would be necessary to construct a 500-kV transmission line and terminal switching facilities to provide a system capable of daily starting of the motors. The annual cost increase to provide a 500-kV system for the plant was estimated to be $50,000.

Across-the-line starting was selected as an acceptable alternate method to start the motors if the motor-generator sets (selected method) were not operable. The high annual cost of a 500-kV system and the uncertainty of designing a motor for repeated across-the-line starts were the major factors in rejecting this system for the normal starting method.

Reactor Starting. The motor is started at a reduced voltage as an induction motor. Voltage is then increased by steps as the motor accelerates. As synchronous speed is approached, excitation is applied and the motor synchronized. Various voltage steps are obtained by using reactors in series with the motor windings. As the motor speed increases, reactance is switched out of the circuit in steps, thereby increasing the voltage across the motor terminals. Voltage steps also could be obtained with multiple taps in the secondary of the power transformers.

Reduction of voltage on the motor terminals during starting reduces shock on the stator windings which would eliminate much uncertainty regarding ability to design a motor for repeated starting. The use of reactor starting results in increased space requirement, capital costs, and maintenance costs.

Induction Frequency Changer Starting Set. This procedure uses a wound-rotor motor and synchronous generator. It utilizes the principle that when having the rotor (primary) winding energized from the 230-kV bus (through a transformer), voltage and frequency in the stator of the wound-rotor motor approach zero as the set approaches synchronous speed. The pump motor is connected to the stator circuit of the wound-rotor motor when the M-G set is rotating at synchronous speed. The synchronous generator is then gradually loaded with high-resistance loads, causing the set to slow down. As the set slows, voltage and frequency in the stator are increased, which causes the pump motor to start and accelerate.

This starting method produces a minimum disturbance to the utility system and minimum shock to pump motor windings; however, high first cost and maintenance will result. The main objection to this method of starting was the lack of experience in the manufacture and operation of this size equipment for this application.

Capacitor Starting. The motor is started as an induction motor, accelerated, and synchronized to the line. Capacitor banks are switched out of the circuit as the motor accelerates to equalize the var component of the motor starting kVA.

The motor experiences maximum heating and winding stress during starting. Transient currents and voltage harmonics may be introduced into the line, although excessive voltage dips will be eliminated. Capacitor banks of the required rating have not been built. Space and seismic requirements would cause considerable cost increase for the bus and capacitors.

Hydraulic Turbine and Generator Starting. This is a reduced-frequency method of starting using a pelton-type hydraulic turbine and a synchronous generator connected electrically to the pump motor. Water is passed through the turbine to accelerate the generator and motor. Excitation is applied to synchronize the two electrical machines at a reduced speed.

Starting severity on the motor is reduced to a minimum and line disturbance is also at a minimum. All equipment is within required experience limits.

The main disadvantage of this method is cost. Hydraulic requirements for the turbine results in arrangement problems with the hydraulic passages and the building structure. Water supply at a high head is required for the initial starts.

Reversible Pump-Turbine Starting. This starting method utilizes a pumping unit operated in reverse as a turbine-generator to supply power to a pump motor. The pump motor is connected electrically to the generator and started at reduced frequency and brought up to synchronous speed by increasing reverse water flow in the pump (turbine).

Advantages of this method are the lack of voltage surges in the transmission line and the minimum severity of starting duty on motors. Costs would be low.

The main problem is the lack of sensitive speed control on the unit being used as a turbine-generator. Throttling water flow with a spherical valve is not considered satisfactory because of cavitation and lack of adequate control. The second main disadvantage is the inability to start the last unit. Whenever full pumping is not required or when a spare unit is available, the last required unit may be started by this method. At other times, the last unit must be started across-the-line. This is objectionable because of the utility requirements and duty on the motor. The number of starts made while placing the plant in operation would have made the reversible pump-turbine starting a poor selection.

Speed Control System for the Motor-Generator Sets

The speed control system for each M-G set consists of a liquid rheostat, a heat exchanger, electrolyte pump, control unit, rotating amplifier, and pilot motor. The liquid rheostat is connected in the secondary or rotor circuit of the wound-rotor motor to provide smooth and stepless acceleration of the M-G set and pump motor (Figure 590).

In selecting the elements of the speed control system, consideration was given to a grid resistor as an alternate to the liquid rheostat. The grid resistor would be switched in steps to regulate the speed of the M-G set. The advantages of the liquid rheostat were considered to be stepless speed control, no capacity limit, ease of dissipating heat, and directly comparable equipment already designed and in use. The disadvantage was that switching of the grid resistors causes power surges which may exceed the limit set by the utility company.

After placing the liquid rheostat in service, experience demonstrated the need to control the temperature of the electrolyte. Different temperatures of the solution caused a varying resistance and erratic action of the liquid rheostat. Timing of the control circuits was affected adversely. Both heaters and coolers were installed to assist in maintaining a more uniform temperature.

Excitation Systems

Two excitation systems are utilized for each motor. One system has a direct-connected exciter on the pump motor for use after the motor is started and synchronized. The second system consists of two separate motor-generator sets to provide excitation during starting of the pump motor. A bus system provides the flexibility to connect either excitation M-G set to any pump motor during starting. Normally, one M-G set will provide service to the west wing and the other M-G set to the east wing. Excitation switchgear and voltage-regulating equipment complete the excitation systems.

Consideration was given to three types of excitation systems: (1) a single, separate, excitation system for all units; (2) individual direct-connected exciters; and (3) individual static exciters. Since the decision was made to synchronize each pump motor at a reduced frequency with the generator of a M-G set, the use of direct-connected exciters during the starting cycle was precluded since the excitation voltage would not be high enough at the reduced speeds. Although necessary for starting, the separate excitation system was not considered to be most suitable for normal motor operation. Investigations of plants designed prior to Edmonston had concluded that the reliability of a direct-connected exciter was the major factor in selecting the direct-connected system. The additional complication of starting motors on the same bus with running motors indicated that selection of two excitation systems was the most desirable.

From investigations during design of other plants, it was concluded that manufacturing and operating experience with static exciters was too limited. The adaptability of static exciters to motors with horsepower ratings as large as Edmonston was even more indeterminable.

230-kV Interconnections

The 230-kV facilities consist of a switchyard, two transformer yards, and associated equipment.

The switchyard has a main-and-transfer bus design containing power circuit breakers, a transmission line disconnect switch with grounding blades, disconnect or isolating switches, potential devices, lightning arresters, and high-voltage revenue metering equipment (Figures 591 and 592).

Figure 590. Liquid Rheostat

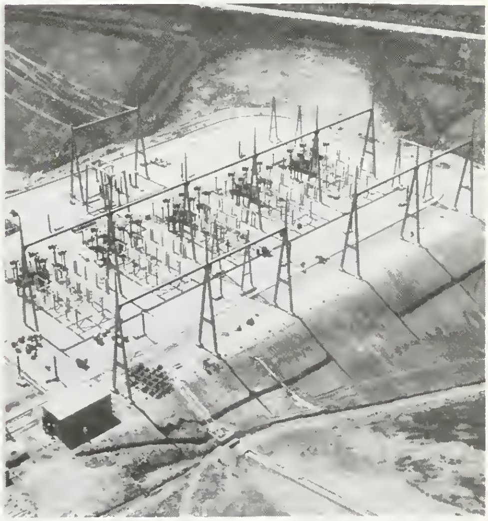

Figure 591. 230-kV Switchyard

One transmission line supplies power to the switchyard. Four 3-phase lines convey power from the switchyard to the transformers at the Pumping Plant (Figure 593). Two transformers are connected to each line through a disconnect switch at the transformer.

Bus arrangements considered were the main-and-transfer, ring, and breaker-and-one-half. The main reason the main-and-transfer arrangement was selected was the terrain around the plant allowed the yard to fit between two hills without excessive cuts. The narrower depth of the yard allowed less earthwork. This bus arrangement gave adequate flexibility for switching and maintenance. The selected arrangement also allows for future expansion with minimum costs. A second transmission line may be required. It also was considered possible that other pumping plants in the Project may be supplied from this switchyard.

Selection of Motor Switchgear

The choice of switchgear for operating the motors was either station-type air-blast breakers or the metal-clad switchgear with lower interrupting capacity and longer maintenance-free life. The station-type breaker was selected primarily because of its higher interrupting rating (Figure 594). Whenever a motor is started, there is a short period of time that the pump motor and the wound-rotor motor are both connected to the utility system. A short circuit at the wound-rotor motor requires a breaker to have an interrupting capacity of 2,500 MVA. Although this hazardous period is brief, the decision was made to take the safer and more conservative approach and use station-type breakers. Operating experience has demonstrated that the breakers will operate without maintenance for a much greater time than was originally anticipated.

Bus Duct

Isolated-phase bus duct was selected for installation after consideration of the alternatives of cable, nonsegregated, segregated, and isolated-phase ducts (Figure 595). These studies progressed concurrently with the study to select the type of breakers.

Although isolated-phase bus is the most expensive of the alternatives, it is also the most reliable. After selection of the station-type breakers, it became more desirable and consistent to use the isolated-phase duct. Phase spacing of the switchgear and bus is identical, making it unnecessary to design special terminations for the bus. Bus type, insulation, and supports are the same with the selected bus and switchgear. The isolated-phase bus duct has the same system integrity as that of station-type breakers.

Motor Thrust Bearing Problem

Soon after the pumping units were placed in operation, high temperatures in the bearing shoes were recorded and a thrust bearing was wiped. All bearings displayed the same problem. High-pressure pumps for forcing oil between the shoe and runner during starting and shutdown were specified in the original motor specification. The bearings also were specified to sustain starting friction without use of the pumps. To prevent overheating, the manufacturer chose to run the high-pressure oil pumps continuously during operation. This procedure was followed for several months while the manufacturer experimented and tested modifications to the oil-to-water cooling system. Recently, an attempt was made to start with the high-pressure oil pump operating, then shut down as the motor accelerated. The test was not successful and resulted in wiping the thrust bearing. Corrective measures still are being studied at this report date.

Figure 592. Revenue Metering Equipment

Figure 593. Transformer Yard

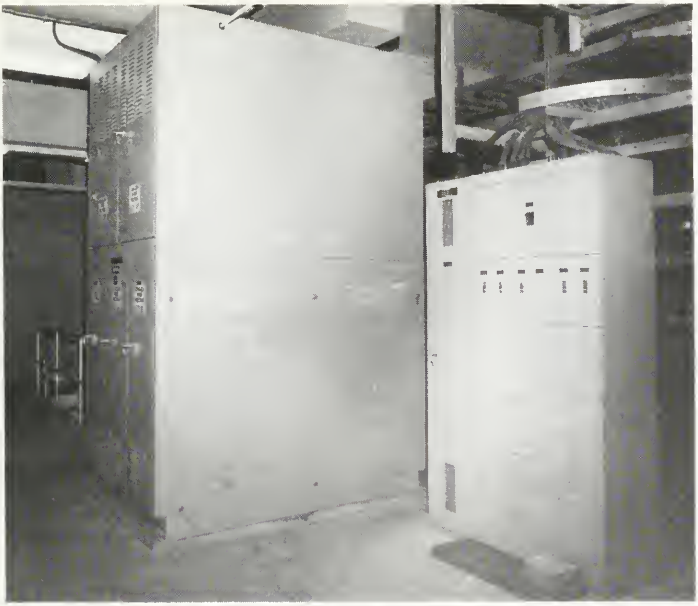
Figure 594. 14.4-kV Motor Circuit Breaker


Figure 595. Outdoor Iso-Phase Bus

Figure 596. Aerial View of Plant Construction

Construction

Contract Administration

General information about the various contracts for the construction of A. D. Edmonston Pumping Plant is shown in Table 12.

The principal construction contracts were Intake Channel Excavation, Specification No. 66-38; Discharge Lines, Specification No. 67-02; Plant, Specification No. 67-33; and Completion Contract, Specification No. 69-04 (Figure 596). There were numerous other construction contracts, and some of the individual equipment contracts rivaled the major construction contracts in cost as well as special problems, both in the factory and at the job site. These included the motor contract, Specification No. 67-58, for 11 80,000-hp motors and two motor-generating starting sets, and the two main pump contracts, Specification No. 67-24 for seven eastside pumps and Specification No. 67-56 for four westside pumps. Extensive model tests were

TABLE 12. **Major Contracts—A. D. Edmonston Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Tehachapi access roads	63-19	$559,598	$570,880	--	7/ 9/63	6/17/64	Wm. H. Schallock
Adit for discharge lines	65-56	591,707	941,338	$69,998	1/31/66	6/19/66	Gates & Fox Co., Inc.
Intake channel	66-38	5,051,040	5,022,087	12,764	8/10/66	10/13/67	Griffith Co.
Discharge lines	67-02	31,225,125	39,198,799	1,048,849	2/20/67	9/30/71	Perini Corp., Morrison-Knudsen Co., and Brown & Root, Inc.
Discharge valves	67-03	4,599,228	6,920,252	1,331,131	3/20/67	10/22/73	Allis-Chalmers Mfg. Co.
East wing pumps (7)	67-24	11,737,620	14,197,017	407,504	11/ 1/67	5/20/74	Baldwin-Lima-Hamilton
Pumping plant construction	67-33	19,638,790	22,312,683	2,772,716	8/ 2/67	8/13/70	Guy F. Atkinson Co.
West wing pumps (4)	67-56	6,349,998	7,700,000 (Est.)	84,880*	11/14/67	12/74 (Est.)	Allis-Chalmers Mfg. Co.
Motors and motor-generator sets	67-58	7,629,691	9,745,000 (Est.)	150,843*	12/ 8/67	12/74 (Est.)	Westinghouse Electric Corp.
Power transformers	68-11	2,312,019	2,616,330	178,959	3/ 7/68	10/22/71	Westinghouse Electric Corp.
Power circuit breakers	68-13	390,989	434,000 (Est.)	4,788*	3/ 7/68	12/74 (Est.)	General Electric Co.
168-inch butterfly valves (2)	68-14	554,951	696,634	49,816	6/24/68	8/ 5/71	Guy F. Atkinson Co.
14.4-kV isolated-phase bus and motor-operated disconnect switches	68-20	1,056,360	1,160,000 (Est.)	15,165*	5/15/68	4/29/74	General Electric Co.
Tehachapi surge tank	68-22	1,181,916	1,266,660	45,740	4/ 3/69	8/16/71	Perini Corp., Morrison Knudsen Co., and Brown & Root, Inc.
65-ton gantry crane	68-25	187,450	196,807	—15	9/13/68	1/15/70	M. P. McCaffrey, Inc.
Bridge cranes (including Pearblossom Pumping Plant)	68-32	829,400	882,679	14,774	2/20/69	8/26/70	Crane Hoist Engineering & Mfg. Co.
Strong-motion acceleration monitoring system (including Castaic Dam and Wheeler Ridge Pumping Plant)	68-38	106,382	144,673	23,985	10/ 8/68	8/ 4/69	Geo-Recon, Inc.
15-kV switchgear	68-42	869,986	975,000 (Est.)	14,087*	10/ 8/68	12/74 (Est.)	General Electric Co.
Switchboards	68-43	474,638	520,392	25,809	12/10/68	11/21/71	General Electric Co.
Station service equipment	68-52	457,415	532,000 (Est.)	17,561*	3/20/69	12/74 (Est.)	Westinghouse Electric Corp.
Completion contract	69-04	5,542,075	8,357,539	1,836,206	6/12/69	6/ 4/73	Dravo Corp.
10-ton gantry cranes	69-06	149,000	155,929	703	4/ 4/69	12/14/70	Fulton Shipyard

* As of November 1974

conducted under contract before manufacturing of the pumps actually to be supplied was undertaken.

First construction began in July 1963 on Tehachapi Access Roads under Specification No. 63-19 followed by Adit to Tehachapi Discharge Line Tunnels, Specification No. 65-56, in January 1966.

Bowl and Intake Channel Excavation

Excavation of the bowl and intake channel for A. D. Edmonston Pumping Plant was started in August 1966 (Figures 597 and 598). During the early phase of excavation, a maximum of ten scrapers was used, assisted by large tractors for ripping and loading. As the channel and bowl became deeper, considerable blasting was required. Slopes in the intake channel and bowl steeper than 1:1 were presplit whenever ripping was ineffective.

After the blasting operations, all material that was too large for loading by scrapers was loaded by rubber-tired loaders into end-dump quarry trucks.

Select material, from the early phase of bowl and intake channel excavation, was used for the construction of the east visitor overlook, the switchyard, and various service roads. Undesirable materials were hauled to spoil areas.

Excavation for Discharge Tunnel Portals

Excavation for the lower portals of the discharge line tunnels was accomplished primarily by blasting after initial attempts at ripping were unsuccessful.

Grading of the upper portal area started in September 1966. Two large tractors with rippers and dozer blades, a tractor with slopeboard, a rubber-tired tractor with dozer blade, a motor grader, and six tractors towing scrapers were used during the excavation. Rock at the face of both upper portals was soft and easily ripped (Figure 599).

Surface Water Removal

A ditch with a bottom width of 12 feet was constructed along the easterly side of the intake channel site. Asphaltic concrete-surfaced interceptor ditches were provided to handle local drainage.

Two 60-inch-diameter, reinforced-concrete, pipe culverts were installed for drainage along the west side of the intake channel. Hand-operated compactors were used to compact the structural backfill for the culverts.

Flows from Escondito Canyon were diverted by a diversion dike away from the pumping plant site in a northwesterly direction into Pastoria Creek through a natural saddle.

During construction, upper portal drainage facilities consisted of one 42-inch and three 18-inch, corrugated-metal, pipe downdrains and two 24-inch, corrugated-metal, pipe culverts. In addition, an 18-inch culvert was installed under the intersection of

Figure 597. Excavation of Intake Channel

Figure 598. Excavation of Plant Bowl

Figure 599. Completed Excavation—Upper Portal for Discharge Lines

the two access roads. These drainage facilities were constructed with three tractors with dozers; one tractor with a backhoe attachment; a front-end loader; a 1,100-gallon water truck; a 10-wheel, 5-cubic-yard, dump truck; and hand compaction equipment.

Ground Water Removal

A temporary, 30-inch, steel, drainage pipe was installed on the 1,286-foot-elevation bench from the southeast corner of the pumping plant bowl, across the southerly face to the southwest corner of the bowl, then northerly to intersect the west drainage ditch. All ground water encountered during excavation for the plant and discharge lines was pumped into this drainage system. A mortar-lined settlement pond was constructed to collect ground water and concrete curing water until the water was pumped into the drainage manifold. After completion of the two sumps for the Pumping Plant, all water below elevation 1,180 feet was directed into these sumps from where it was pumped through 8-inch discharge lines to the settlement pond.

Structural Excavation

Structural excavation started at the northerly end of the pumping plant east wing. In certain specified areas, the final 2 feet of excavation was not removed until just before the placing of a protective gunite covering.

Most of the structural excavation was performed using seven self-propelled scrapers and seven large tractors with dozers. A backhoe, front-end loader, and an end-dump truck were used in confined areas and to remove access ramps. Fine grading was completed with a grader and hand labor.

In the southerly portion of the plant foundation, some blasting was required in the diorite formation. All slopes steeper than 1:1 were presplit but only with partial success.

The ¼:1 and ⅓:1 side slopes in the area of the two sumps were unstable because of highly fractured rock and lenses of sandstone until after the slopes were flattened and the loose and broken rock was scaled off. The overexcavated area was backfilled with concrete to the originally planned slope lines.

In the excavation of the service bay, 27-foot-high vertical slopes were cut adjacent to the "E" and "W" access roads. Because the formation was fractured and unstable, bin-type retaining walls were installed.

Pneumatically Applied Mortar

All final excavated surfaces susceptible to air slaking were covered with a 2-inch layer of mortar. Nearly all of the foundation slopes were treated for both the east and west wings, the extreme easterly and westerly portions of the service bay, and the major portion of the finished cut slope above yard grade behind the plant. The mortar was applied with a gunite machine.

Concrete Operations

Production. A stationary batch plant was used for concrete production. The batching, weighing, and dumping cycle was fully automatic and was completely interlocked to the mixing plant. The four aggregate sizes and the water and/or ice were weighed individually.

All admixtures, with the exception of pozzolan, were batched automatically during the weighing sequence. A dual dispensing system permitted the admixtures to be premixed with either the water or sand, depending on the water-to-ice ratio being used.

The mixing plant consisted of four 2-cubic-yard, front-loading, tilting mixers. After 1½ minutes of mixing, the concrete was discharged directly into 4-cubic-yard hoppers.

Transportation. Freshly batched and mixed concrete was dumped directly into either 2- or 4-cubic-yard concrete buckets depending on placement requirements. The concrete buckets were transported to a position near the placement site along trestle-supported rails on concrete cars pulled by diesel locomotives. Whirley cranes then lifted the buckets from the cars and delivered them to the placement site (Figure 600).

Placement. Concrete placement was started in January 1968 (Figure 601). Structural concrete was placed in approved planned lifts, with a placement scheduled nearly every day. When elevation 1,155 feet was reached, the contractor was able to use two cranes. The smaller crane was used to set forms and deliver reinforcing steel to one wing, while the larger unit placed concrete in the other wing. Because of the pumping plant symmetry, forms were interchangeable between sides.

During concrete construction, many design changes necessitated revisions in the placement, size, and number of reinforcing bars used. When the batch plant was dismantled in October 1969, approximately 189,500 cubic yards of concrete had been placed (Figure 602).

Manifolds

The discharge line manifolds consist of shop-fabricated circular sections of heat-treated manganese-silicon steel. Between August and December 1967, fabrication was suspended pending changes in manifold design that included changing the angle of intersection from 45 to 60 degrees and changing the thickness of some sections. In January 1969, installation of the east discharge manifold began. Stress relieving of the first joint began after nondestructive testing of the field welding. Testing of the east manifold was completed in June 1969 and the west manifold in July 1969. In December 1969, the interiors of both manifolds and roll-out sections were painted.

Figure 600. Construction Progress on Plant Structure

Figure 601. First Concrete Placement for Plant Structure

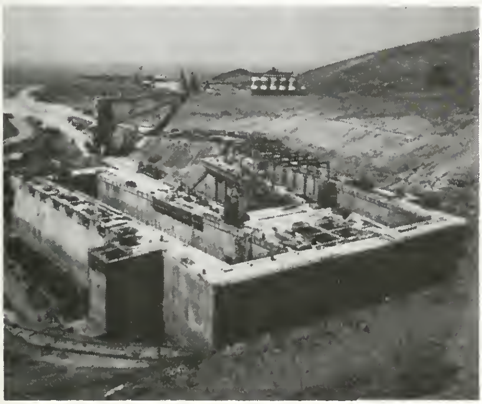

Figure 602. Concrete for Plant Structure Topped Out

Structural Backfill

Initially, diorite was processed for selected structural backfill. Zone 1 material was specified as well-graded diorite with a maximum dimension of 18 inches and not more than 15% passing the No. 4 screen. The maximum allowable dimension of Zone 2 material was 6 inches. In October 1969, the first structural backfill was placed around the embedded east discharge manifold. In April 1970, the difficulty of obtaining suitable material from the designated spoil areas prompted the decision to obtain material from a basalt outcrop after tests determined that the material met specified requirements.

Discharge Line Tunnel Adit

The adit to the discharge line tunnels, in addition to providing a means of access for the construction and maintenance of the discharge line tunnels, was used to obtain additional geologic information needed for design of the discharge lines. A revision in the alignment of a portion of the upper reach of the discharge lines resulted from data obtained during construction of the adit.

The adit tunnel is about halfway up the mountain. A second contract, Specification No. 71-22, was awarded in November 1971 to improve the adit tunnel portal structure support system and ventilation system.

Adit Portal Excavation. Two large dozers equipped with rippers were initially used for portal excavation. As the excavation progressed, the dozers were equipped with moldboards fabricated to a shape and section that facilitated cutting uniform slopes. Material within approximately 15 feet of the portal invert required blasting. Additional blasting was required at the east side of the portal excavation area for drainage sections (Figure 603).

Adit Tunnel Excavation. All drilling and loading of blast holes for tunnel excavation were done from the three working levels of a jumbo mounted on a 35-ton chassis. After each blast, the muck was hauled to the designated spoil area. After mucking operations were complete, line and grade were transferred to the new heading, and the jumbo was brought back to the heading to install steel tunnel supports and timber lagging prior to the next drill cycle. In rock-bolted areas, the rock bolts were installed during the drill cycle (Figure 604).

A concrete footing beam was constructed on either side of all steel-supported sections in the adit, including the portal.

Geologic exploration in the tunnel included installation of rock relaxation meters and diamond core drilling.

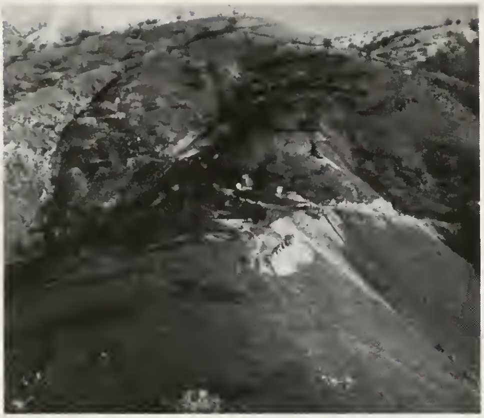

Figure 603. Portal of Adit to Discharge Line Tunnels

Figure 604. Adit to Discharge Line Tunnels

Figure 605. Plant Discharge Lines

Discharge Lines

Tunnel Excavation. After extending the previously built discharge line tunnel adit approximately 120 feet to the intersection with the east discharge line, excavation of the upper east horizontal tunnel was started under Specification No. 67-02. A specially designed, gantry-type, rail-mounted jumbo provided two working decks, with the lower deck being hinged to provide access through the unit for mucking machines and hauling equipment during the mucking cycle (Figure 605). In general, the rock conditions in the upper east horizontal tunnel were as good or better than expected from preliminary investigations, and few problems were encountered during excavation of this section. The contractor averaged 100 linear feet of tunnel excavation per week and installed steel supports throughout.

Initially, excavation for the upper west horizontal tunnel consisted primarily of trimming and squaring the heading face to the line and grade of the west discharge line, where it intersected the adit tunnel. Excavation on the full face was performed using the same methods and equipment as on the upper east horizontal tunnel. In order to stabilize one area where a cave-in occurred, a timber bulkhead was erected and the entire rockfall area was grouted. The grouted mass was then mined when excavation resumed. Other than this cave-in, little trouble was encountered and the contractor averaged 96 feet of tunnel per week.

Due to the restricted size of the lower horizontal tunnels, specially designed truck-mounted jumbos were used in lieu of the larger, rail-mounted, gantry jumbos. Tunnel excavation in the lower horizontal tunnels proceeded during construction of the Pumping Plant. An intermediate muck pile near the portals was used and material was transferred to the disposal site at night, thereby relieving congestion on the service roads. Rock encountered in the lower horizontal tunnels was not as competent as in the upper tunnels. Several minor cave-ins occurred, but progress still averaged about 100 feet per week.

The sequence of operations for the two upper incline tunnels was identical: (1) drill a 9-inch pilot hole from the upper portal down to the intersection with the upper horizontal tunnel; (2) lower a drill stem down the pilot hole, attach a reamer bit, and back-ream a 6-foot-diameter hole; and (3) drive the incline to its full diameter from the top, while the muck falls down the 6-foot-diameter hole. Other than difficulties with alignment of the pilot holes and intermittent plugging of the 6-foot-diameter hole during mucking, excavation progressed at a fairly rapid and uniform rate (Figure 606).

Excavation of the lower incline tunnels was attempted in the same manner as was used in the upper inclines. In the lower west incline tunnel, the pilot hole ended up about 32 feet off alignment at the bottom. Attempts to back-ream the hole to a 6-foot diameter were unsuccessful. Similar problems were encountered in excavation of the lower east incline tunnel. The pilot hole and back-ream method was then abandoned for the lower incline tunnels, and full-face tunnel excavation from the top of the lower inclines was employed. Muck from the excavation of the tunnel was loaded into a 5-cubic-yard muck car at the heading and hauled up to the top of the incline, where it was transferred to hauling equipment. In the lower east incline tunnel, ground water seepage had to be pumped from the excavation. Progress averaged 32 feet per week.

Tunnel Supports. Rock bolts were installed in concentric rings, each consisting of 11 bolts on 4-foot transverse and longitudinal centers. This pattern was used on all horizontal portions and the upper inclines wherever rock conditions justified the use of rock bolts. In areas of poorer rock quality, steel sets were used (Figure 607). Their spacing varied from 2 to 6 feet. All of the inclines and most of the horizontal portions were supported with steel sets. All permanent lagging, block, and spacers were steel, as specified, and a large quantity of this material was installed.

Subinvert Backfill. On the horizontal reaches of the discharge line tunnels, subinvert concrete was placed between the "B" line and a point 2 feet below the bottom of the steel liners. It provided a smoother and better means of access through the tunnels for installation of the liners and transportation of the final backfill concrete.

Steel Liners. Installation of the steel liners for the horizontal tunnel reaches was accomplished by backing the sections into place on a transporter (Figure 608). Sections for the inclines were placed by using a large crawler crane to lift them onto rails laid during the excavation of the tunnels and then lowering them into position with a cable hoist. Special sliding shoes to fit the rails were attached during fabrication of steel sections used on the inclines.

Final Backfill. For the horizontal reaches, tunnel backfill concrete was pumped through an 8-inch slickline and vibrated into place. Groups of four pipe sections were installed and successfully backfilled as a unit. For the inclines, the placing procedure was similar, except only three sections were installed and backfilled as a unit. Concrete was gravity fed through a 6-inch slickline.

Both discharge lines between the Pumping Plant and the portals of the lower horizontal tunnels were encased in concrete. Concrete was pumped into the forms for both encasements.

Grouting. Contact grouting was performed to fill the voids in the arch portion of the tunnels between the concrete backfill and the rock tunnel walls. Consolidation grouting was performed to fill the fissures in the rock surrounding the tunnel.

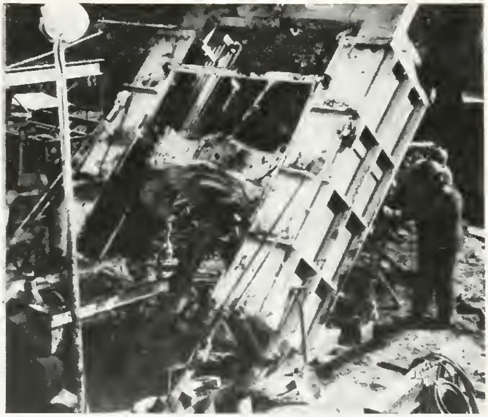

Figure 606. Pilot Hole for Incline Tunnel for Discharge Lines

Figure 607. Plant Discharge Lines—Horizontal Section of Tunnels

Figure 608. Transporter Placing Steel Tunnel Liner

Surge Tank

Foundation. Excavation for the tank base was made to rough grade with a tractor equipped with dozer and ripper. Excavated material was stockpiled for later use as backfill. The area between the north end of the roll-out sections and the south end of the lift-out section was overexcavated about 3 inches and backfilled to subgrade with concrete in order to provide an all-weather work platform.

Concrete was used to backfill the bottom part of the cast-in-place tunnel extension, and then stockpiled earth material was placed and compacted to complete the backfill operation.

A vibratory sheepsfoot roller was used for compaction of backfill material adjacent to the surge tank base, but the material placed had to be reworked to achieve 95% relative compaction.

Steel Assembly. Field assembly and erection were performed for the surge tank shell, the 14-foot-diameter pipe sections and taper sections, the roll-out sections and track assemblies, the wye branches, the 5-foot-diameter bypass system, the 23½-foot-diameter pipe section between the surge tank and the portal of Tehachapi Tunnel No. 1, and the lift-out section.

An oiled sand cushion was placed and compacted over the concrete base of the surge tank. The tank bottom sections were then positioned on top of the sand cushion and welded together, followed by the placement of the bottom, preassembled, shell section. The remaining tank shell sections were then successively placed and welded. Only the vertical seams were completely welded during erection; welding of the girth seams was completed after the stiffener rings were in place and the tank was topped out. As the shell sections were lifted into place, the 5-foot-diameter bypass risers were extended section by section to the top of the tank (Figure 609).

Completion

Enormous quantities of electrical wiring, lighting fixtures, conduit, cable trays, plumbing, small valves, as well as the building superstructure, were installed under the completion contract, Specification No. 69-04.

Installing isolated-phase bus of welded aluminum was difficult. Various design changes, scheduling changes, and field delays due to other contracts which had to be accomplished in a proper time sequence resulted in change orders and increased costs. This contract was completed on June 4, 1973, almost seven months later than originally scheduled.

Field assembly of the 80,000-hp motors and installation and testing of the 48-inch spherical valves and pressure-reducing valves for dewatering the discharge lines were demanding. High downthrust of westside pumps and related motor thrust bearing failures resulted in protracted rework. Required modifications to the pumps, motors, and other mechanical and electrical equipment were discussed previously in this chapter.

Figure 609. Completed Surge Tank

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 610 through 647).

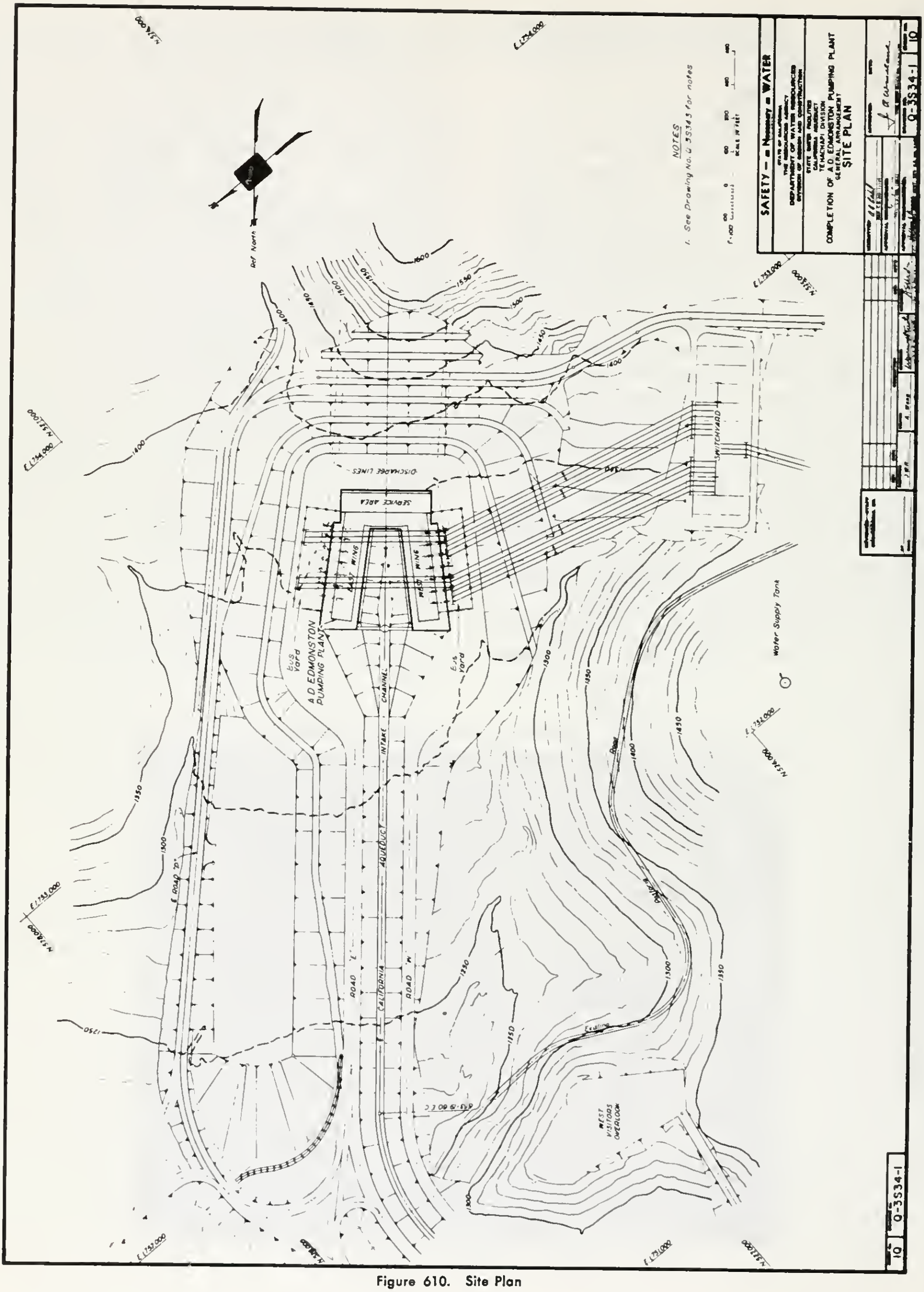

Figure 610. Site Plan

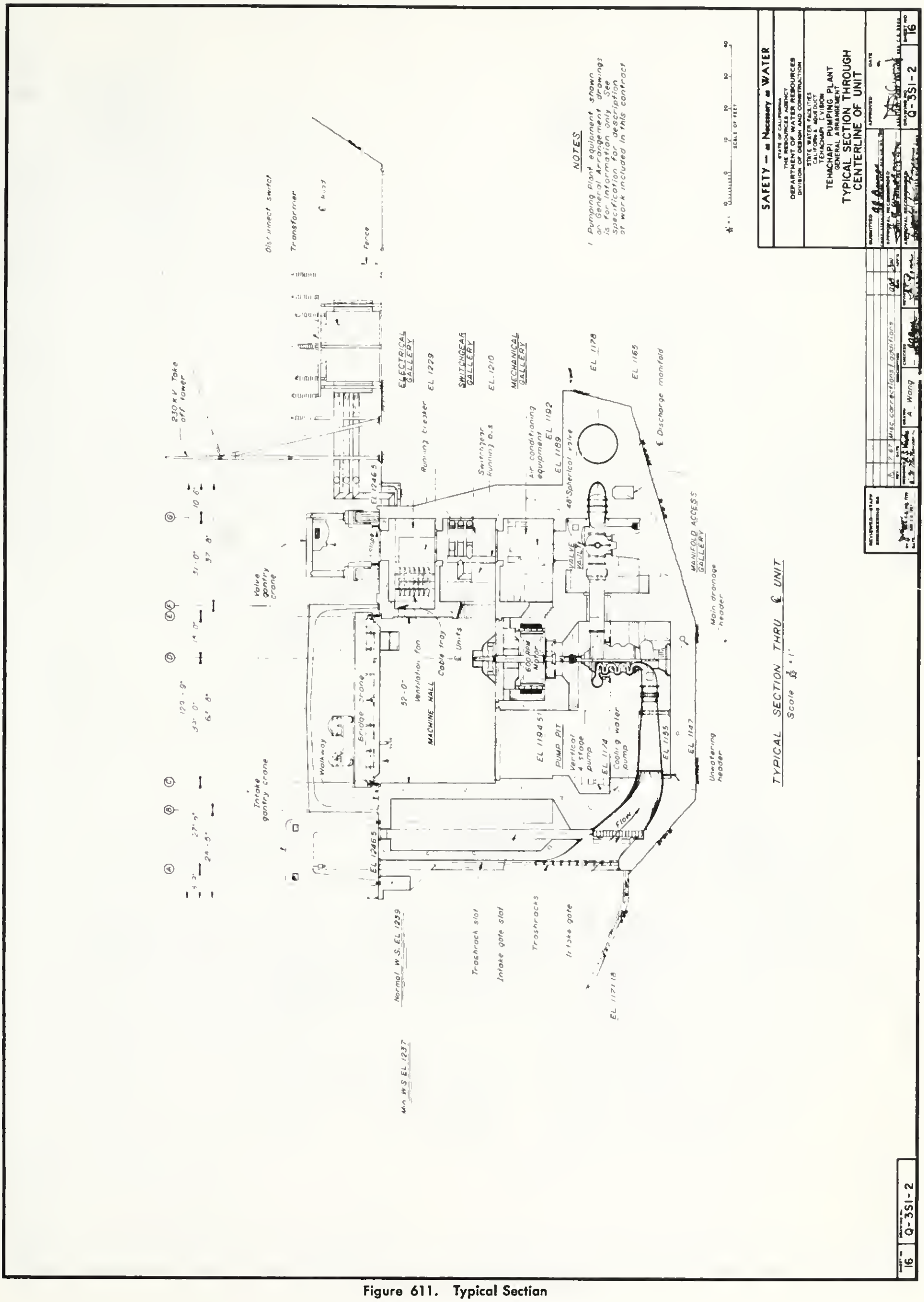

Figure 611. Typical Section

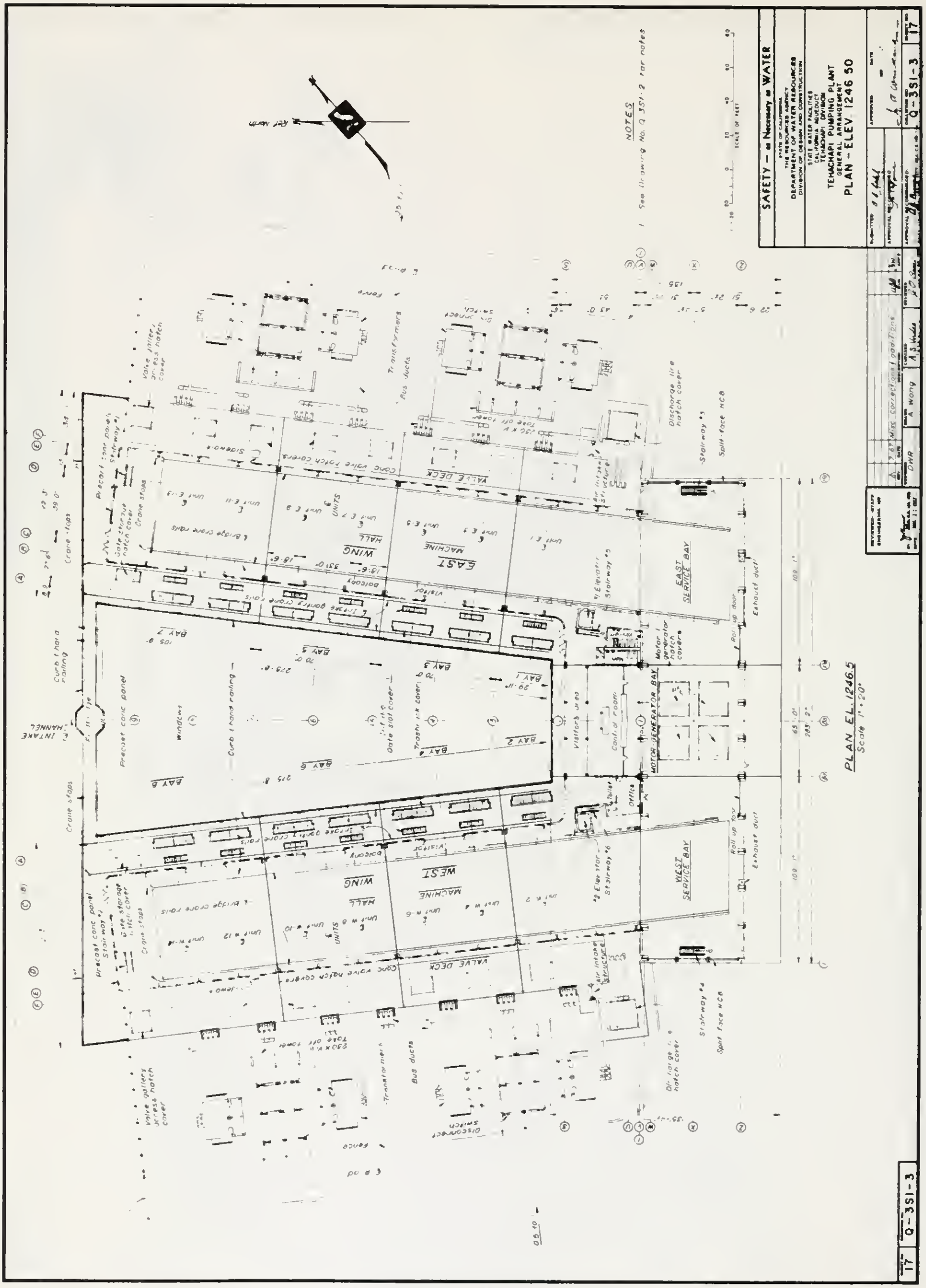

Figure 612. Plan—Elevation 1,246.5

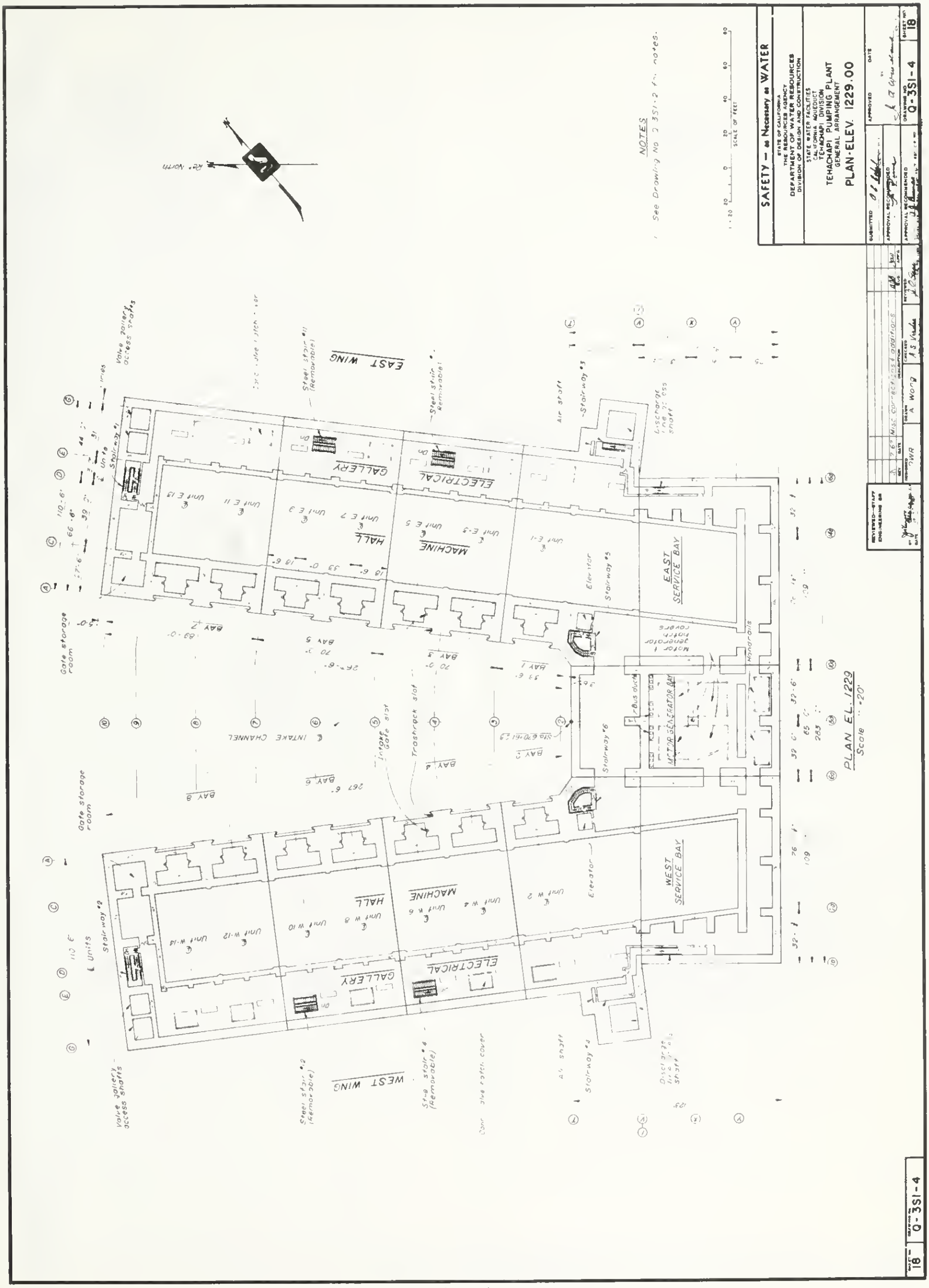

Figure 613. Plan—Elevation 1,229.0

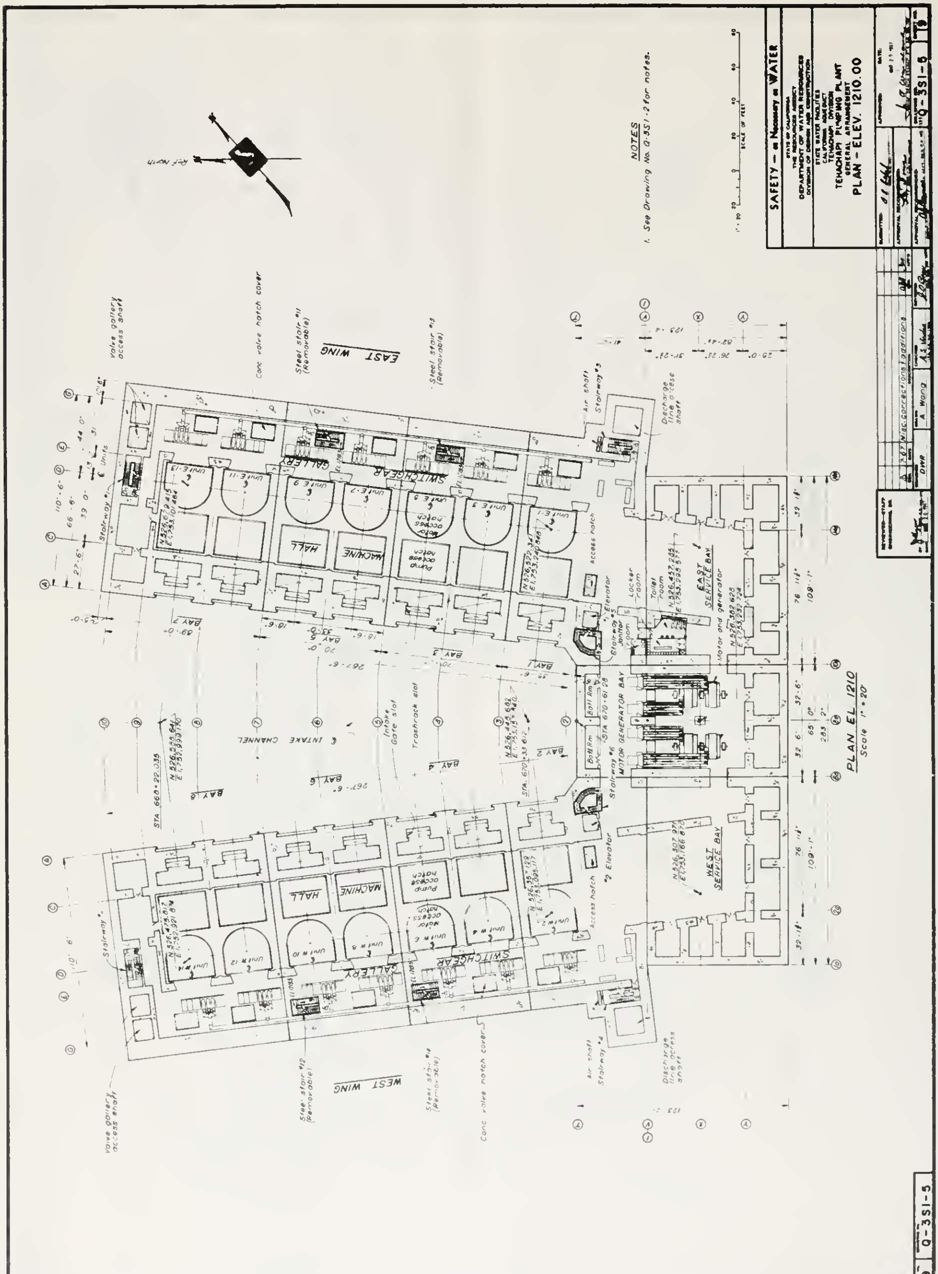

Figure 614. Plan—Elevation 1,210.0

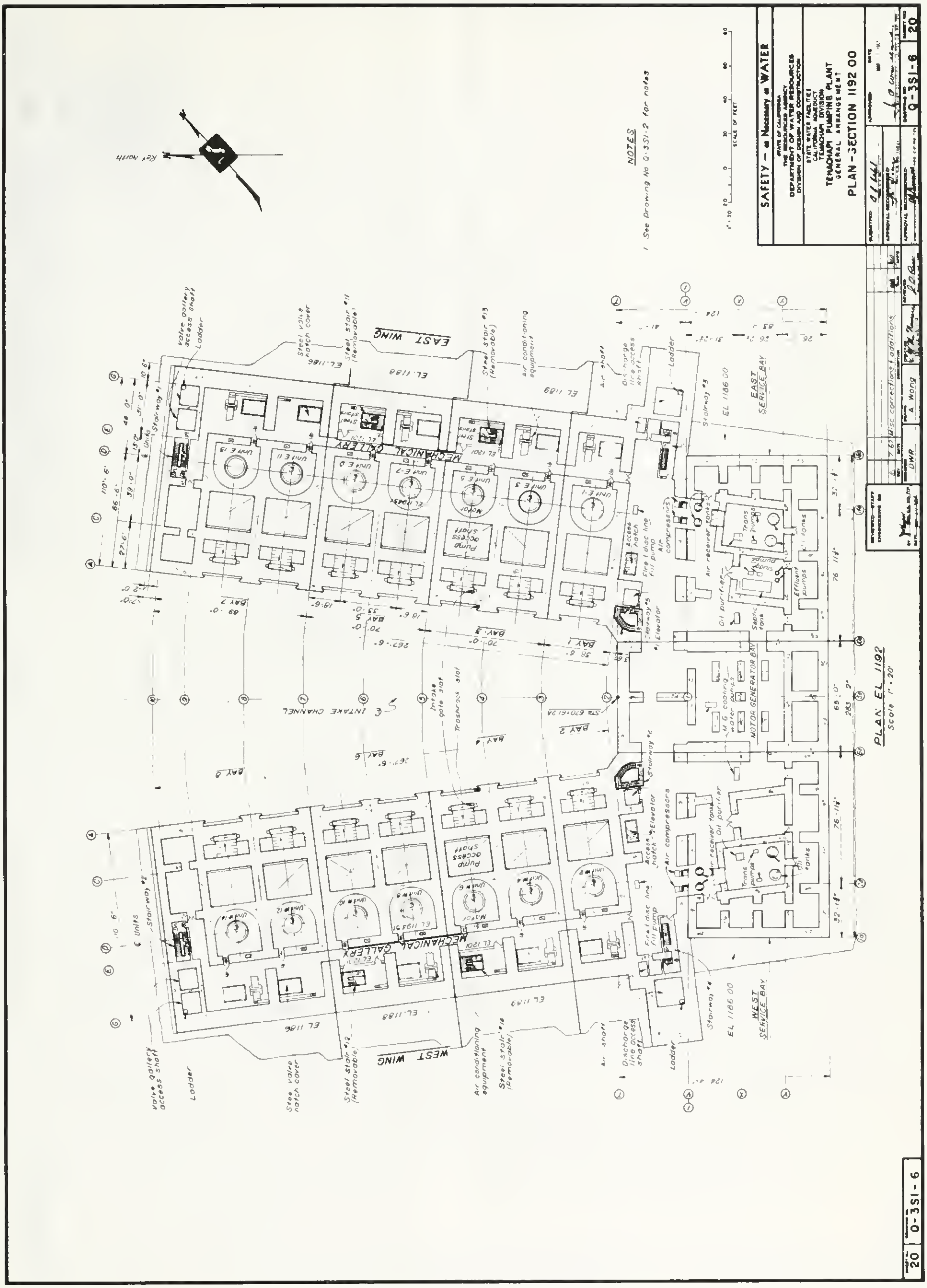

Figure 615. Plan—Elevatian 1,192.0

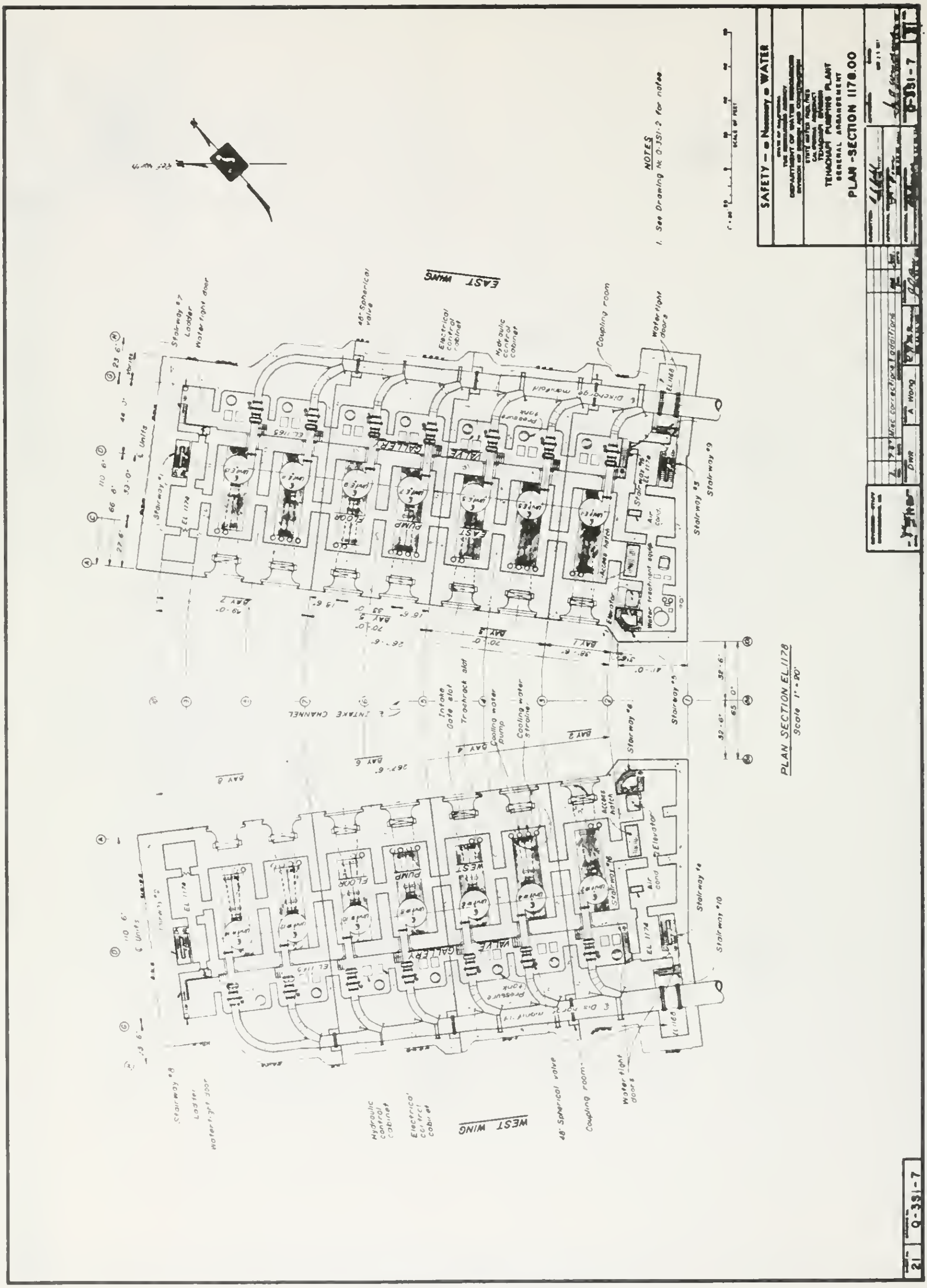

Figure 616. Plan—Elevation 1,178.0

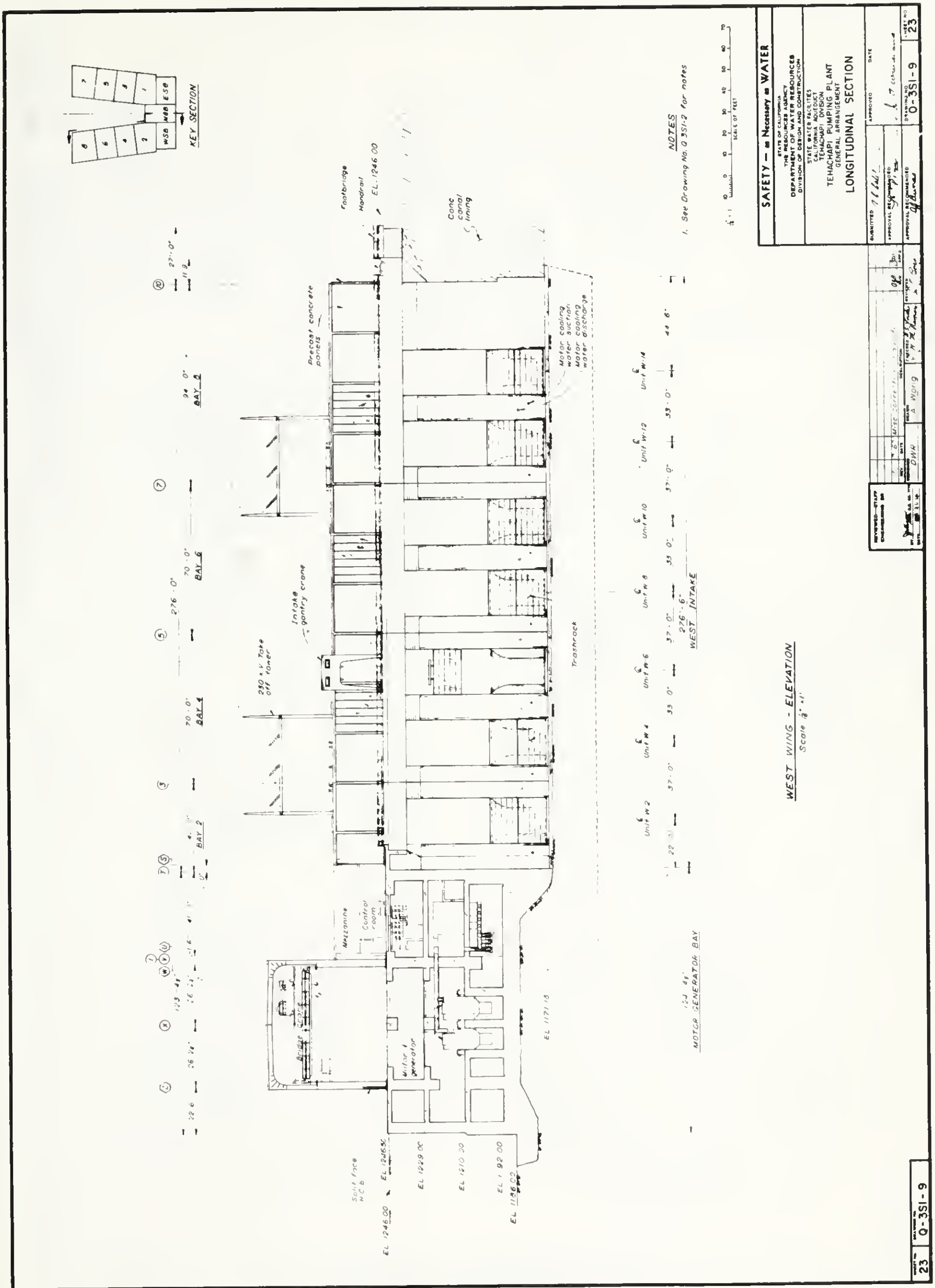

Figure 617. Longitudinal Section

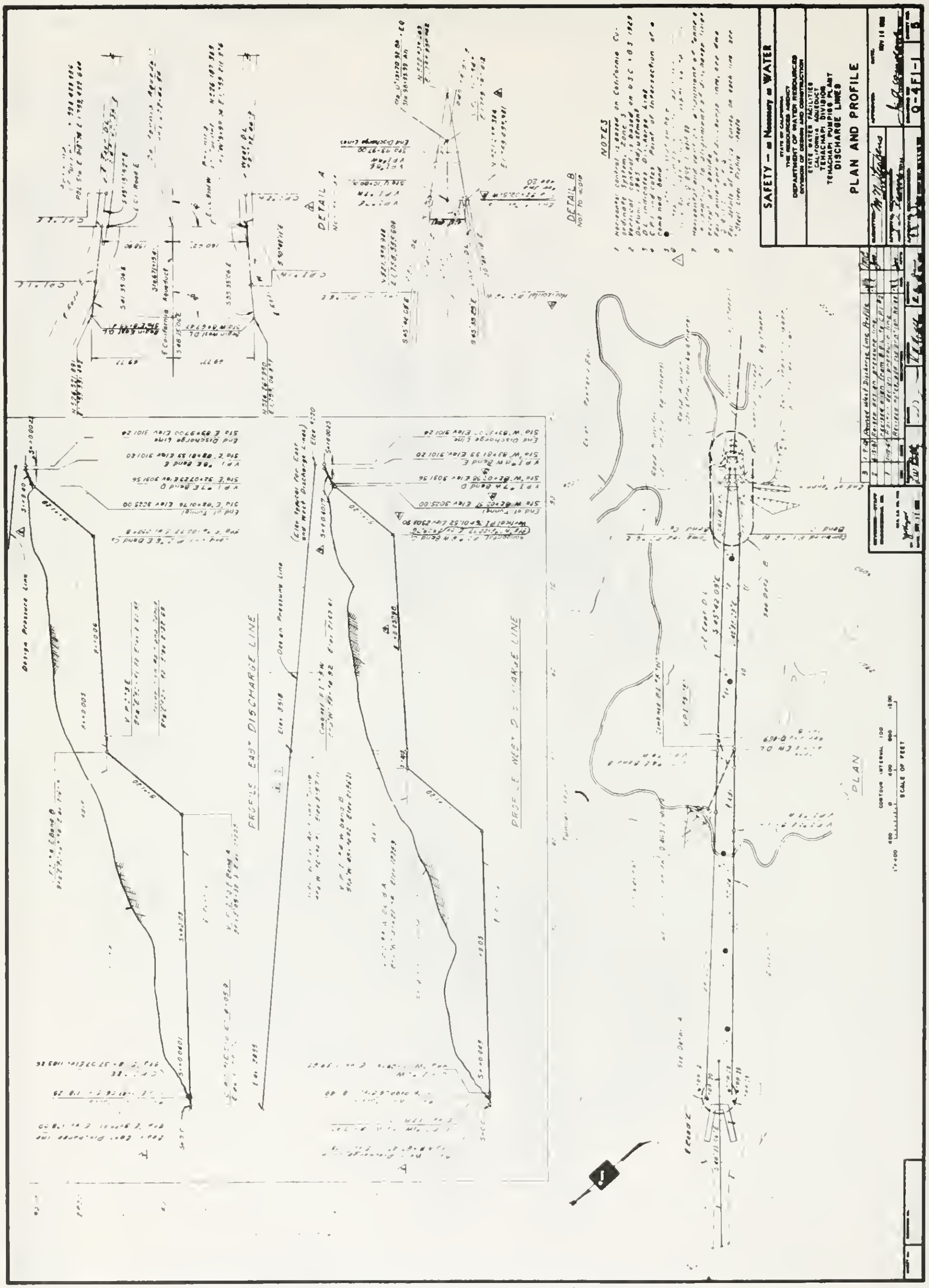

Figure 618. Discharge Lines—Plan and Profile

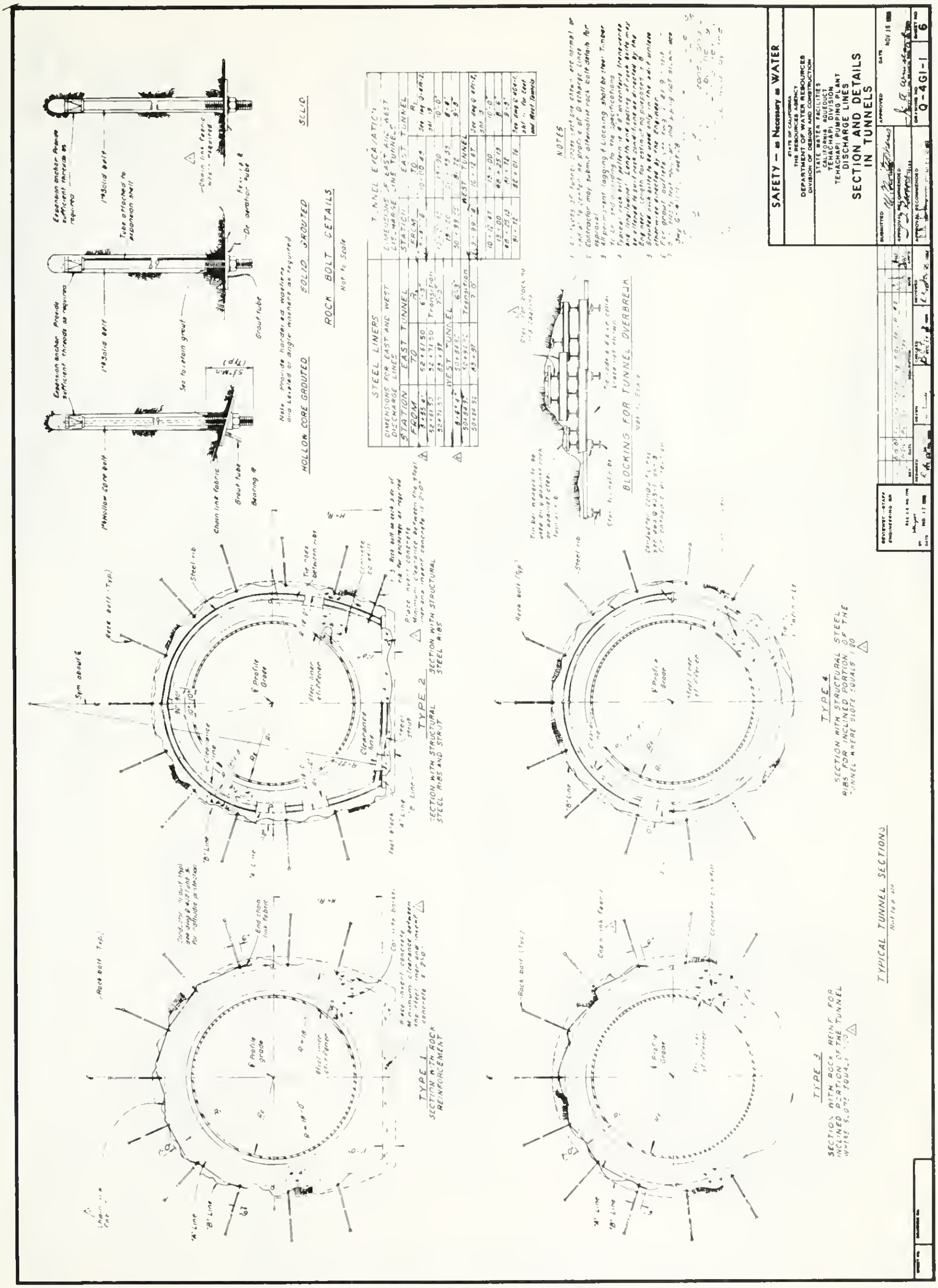

Figure 619. Tunnel—Section and Details

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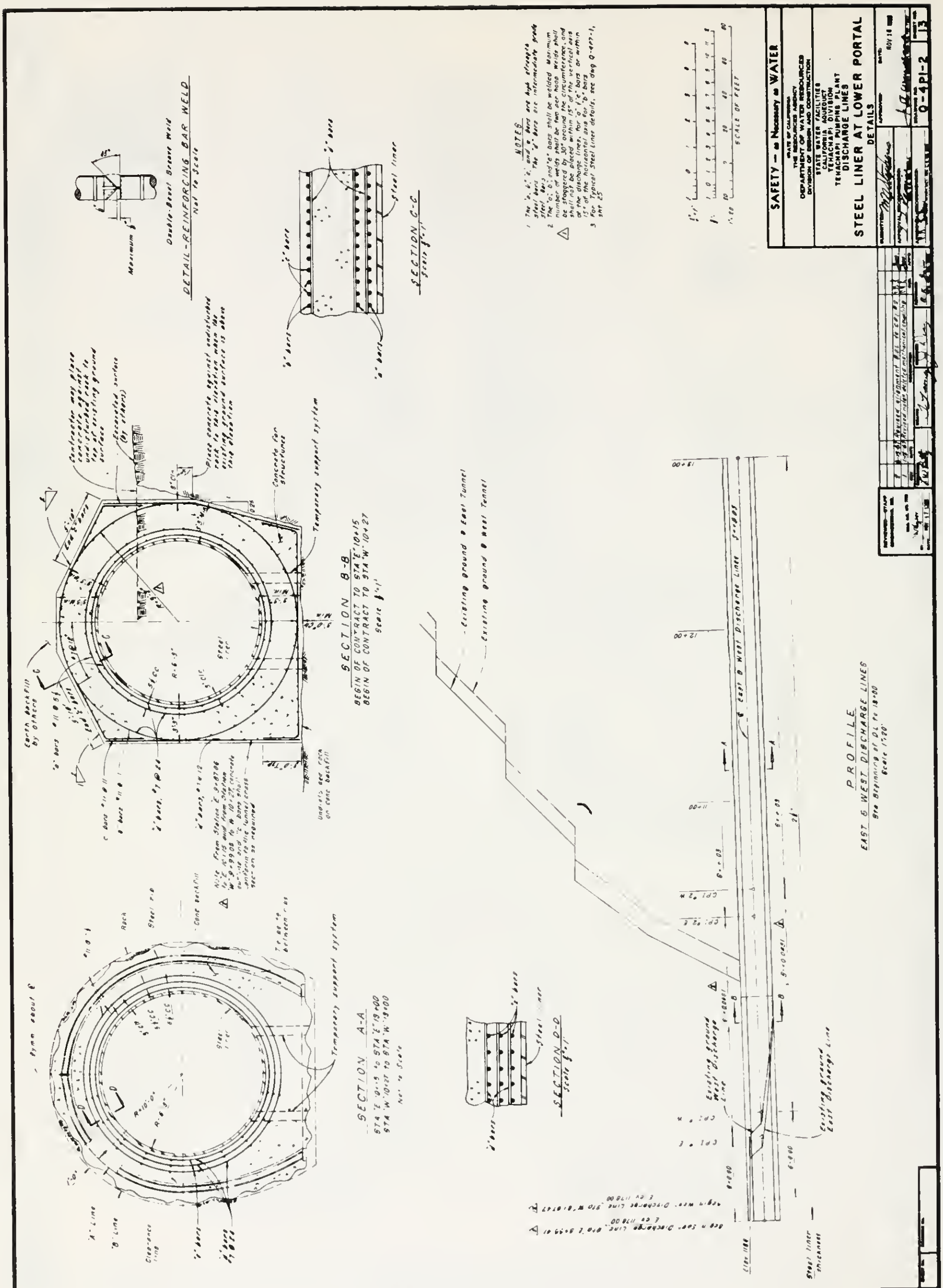

Figure 620. Steel Liner—Details

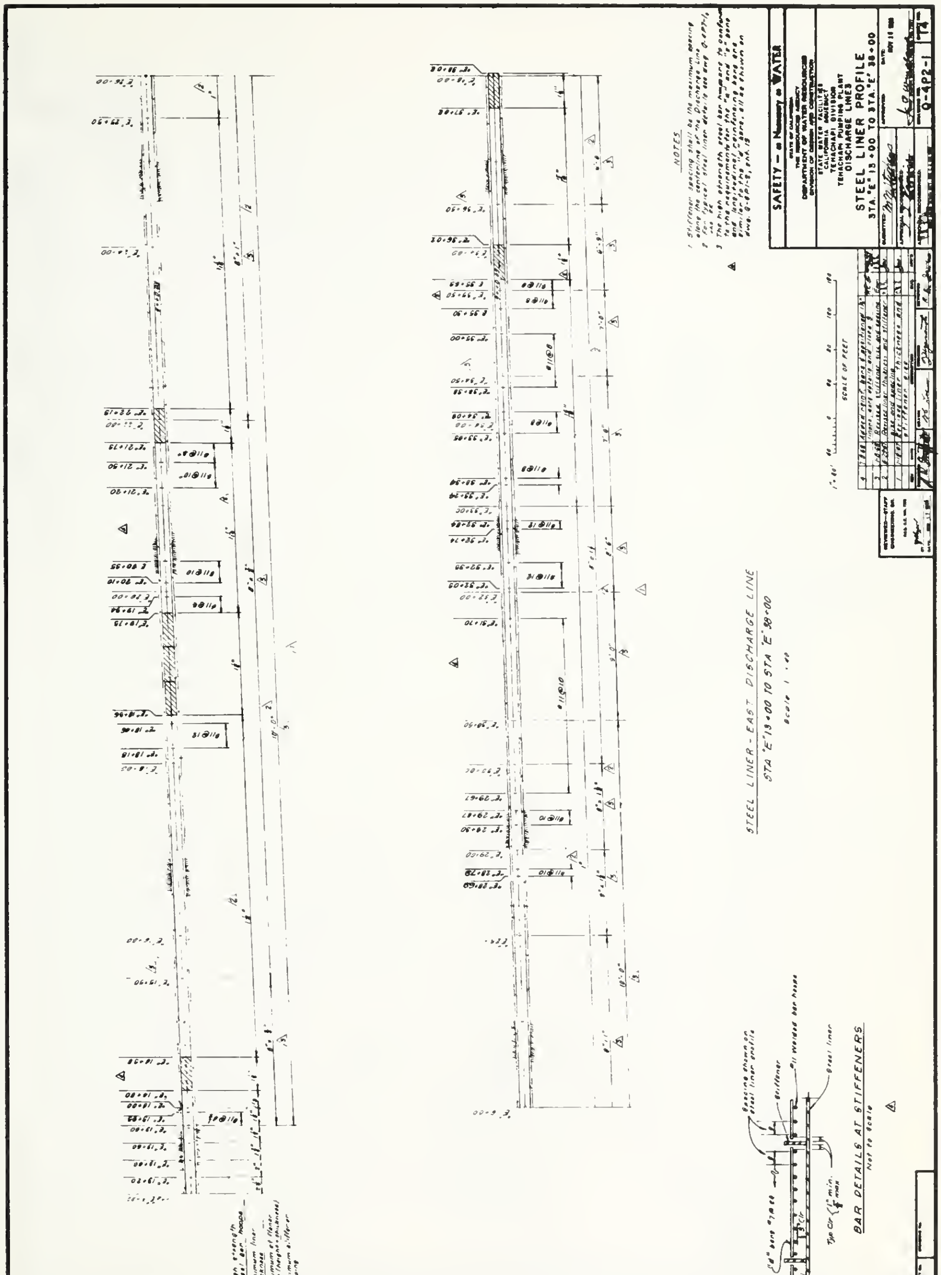

Figure 621. Steel Liner—Profile

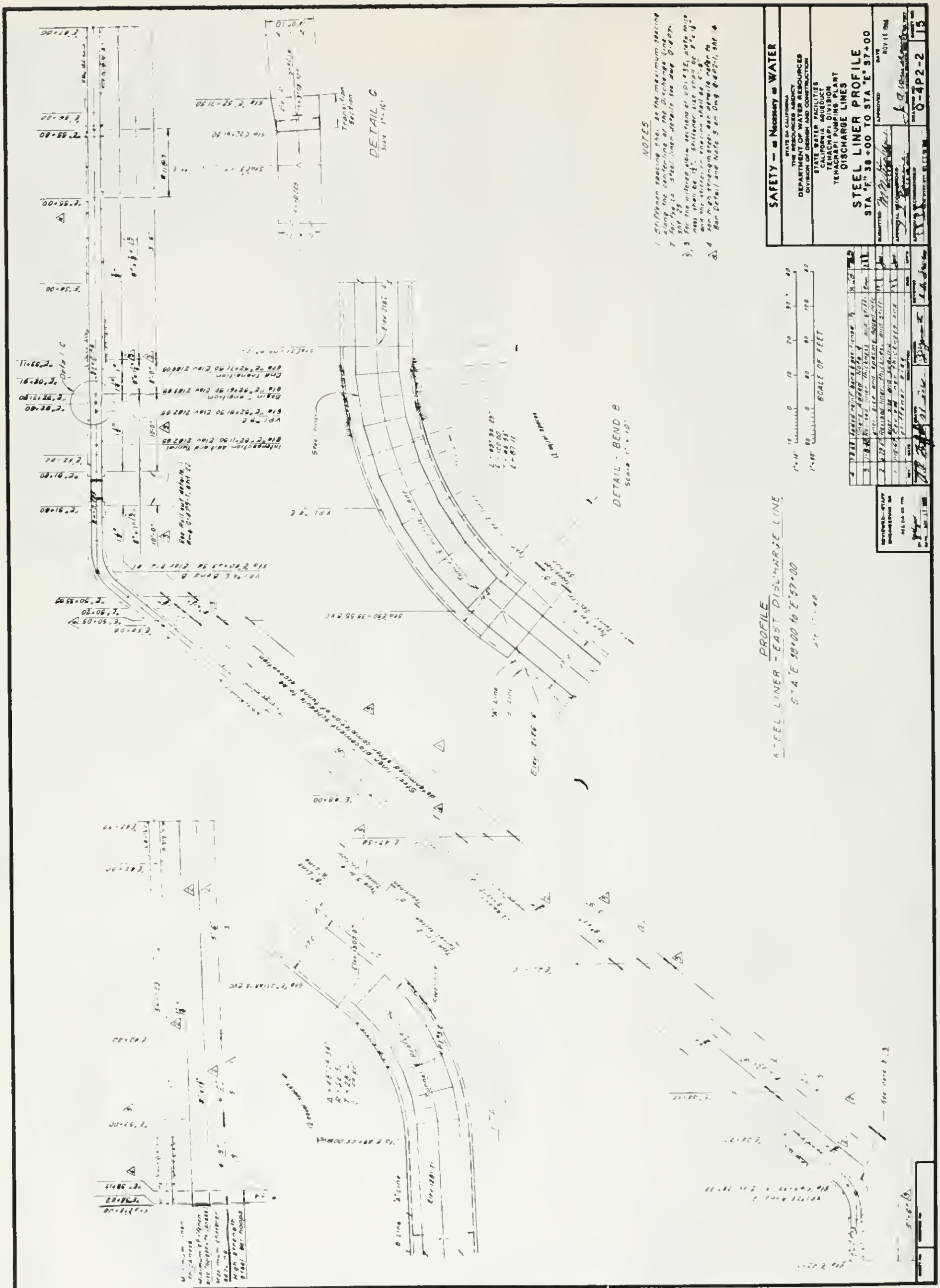

Figure 622. Steel Liner—Profile (Continued)

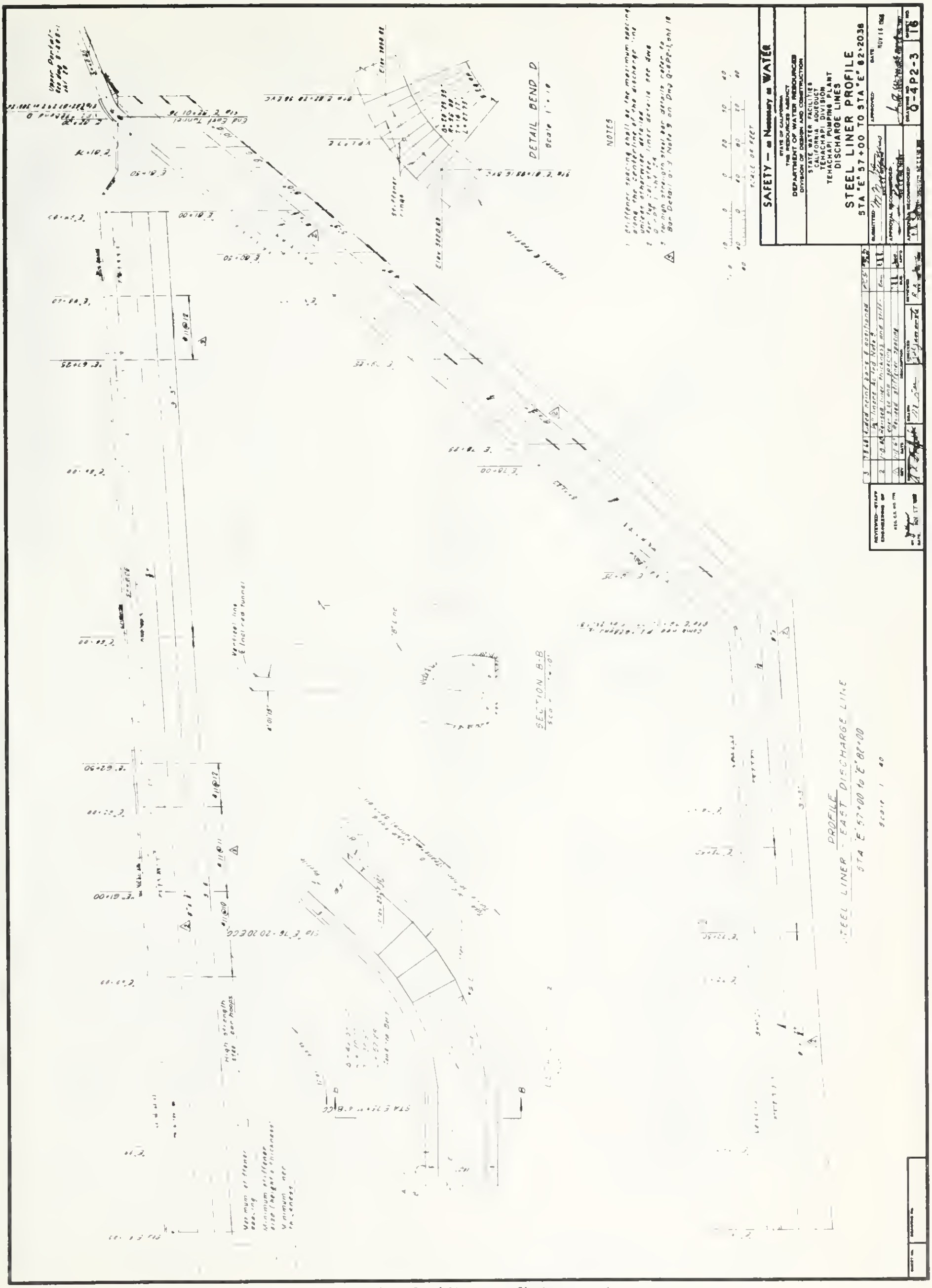

Figure 623. Steel Liner—Profile (Continued)

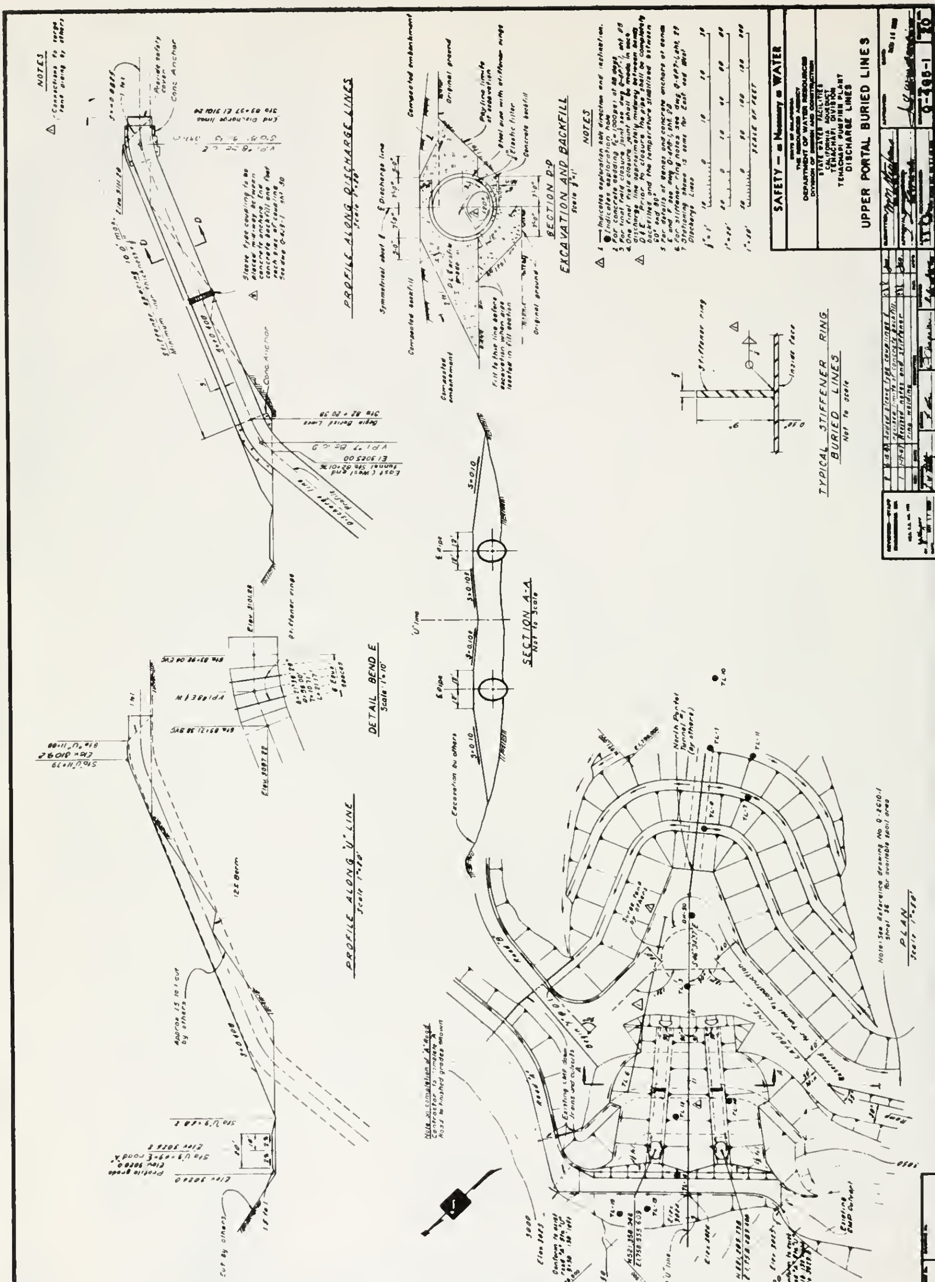

Figure 624. Upper Portal Buried Lines

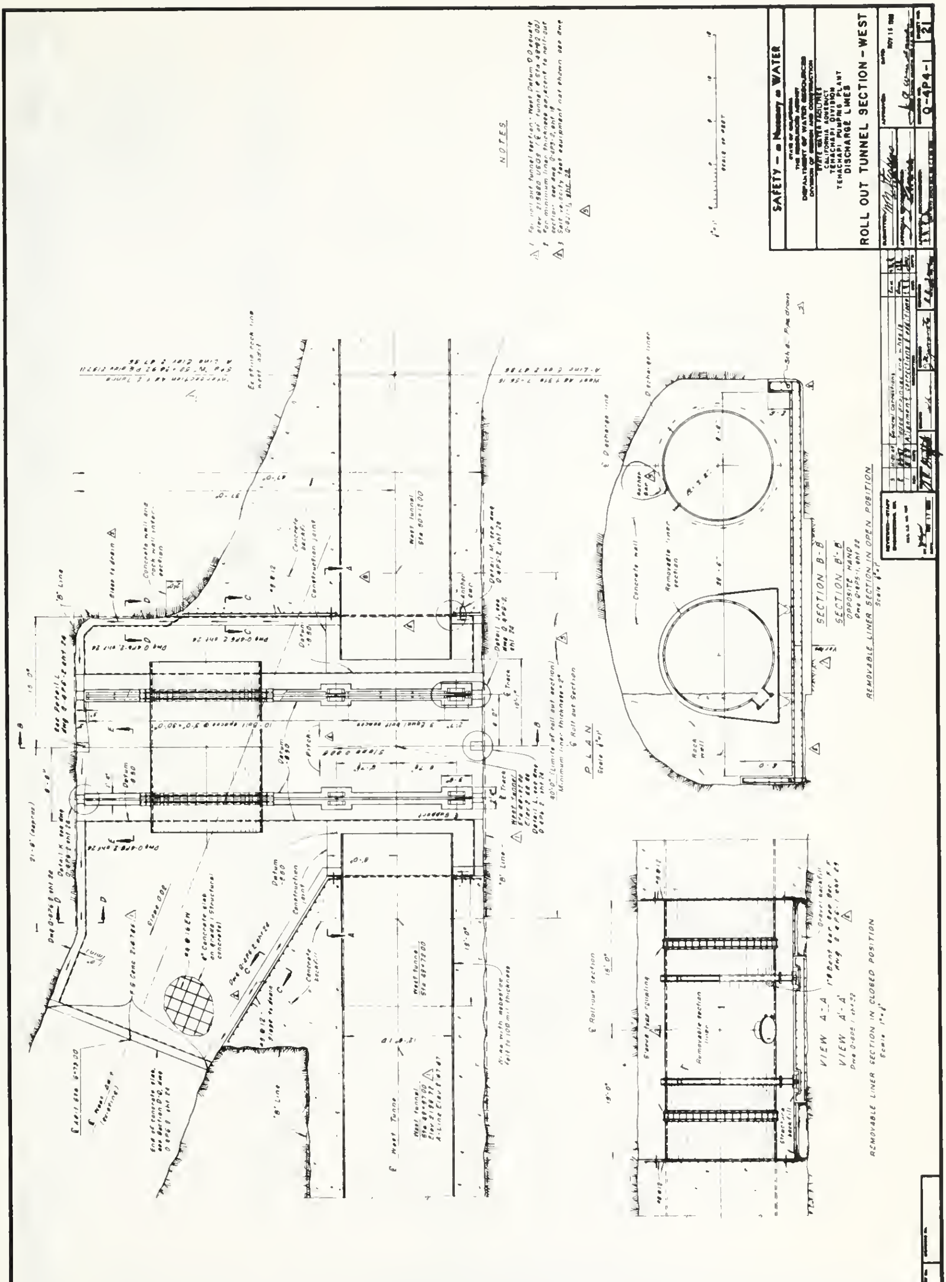

Figure 625. Roll-Out Section—West

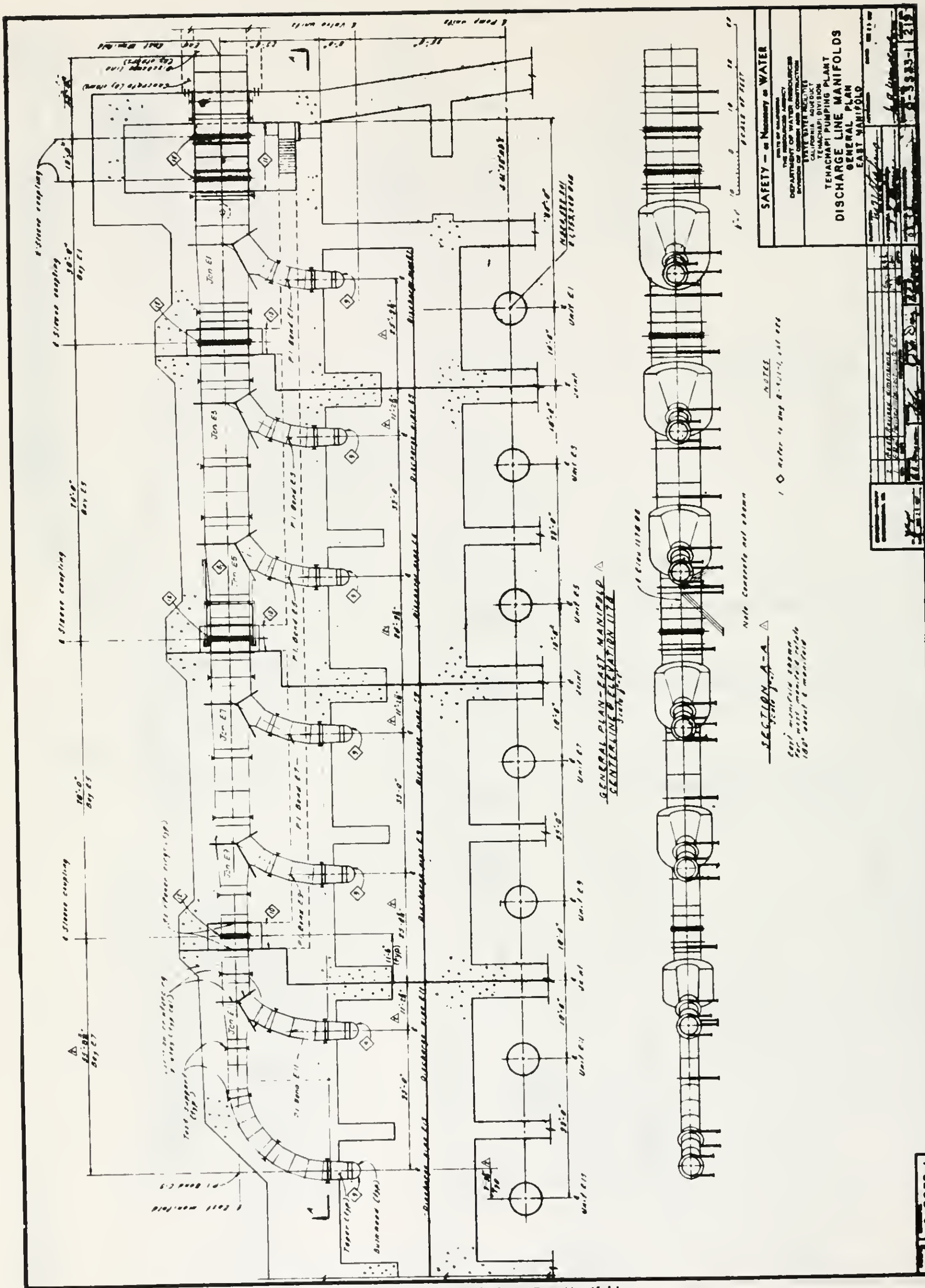

Figure 626. General Plan—East Manifold

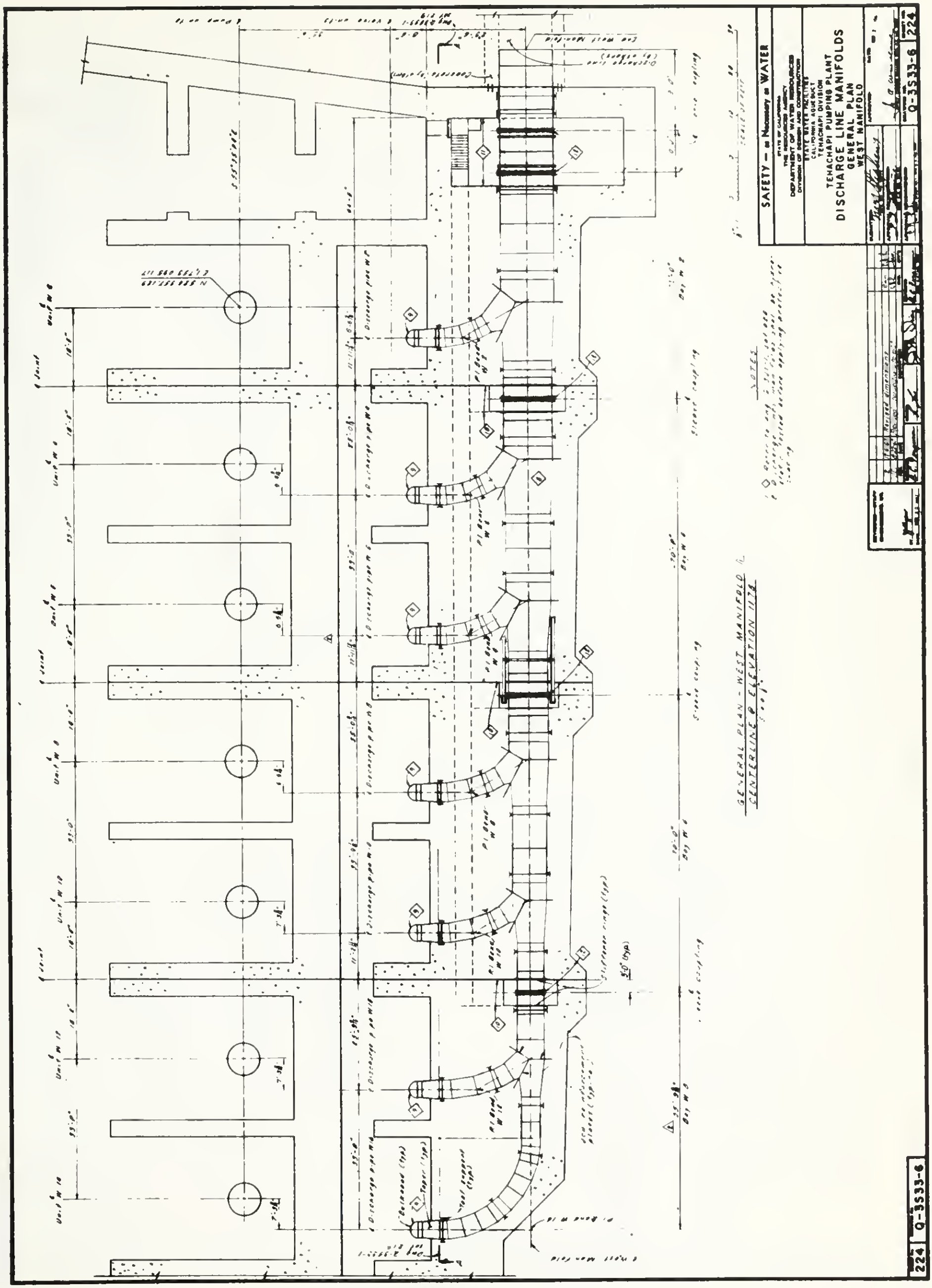

Figure 627. General Plan—West Manifold

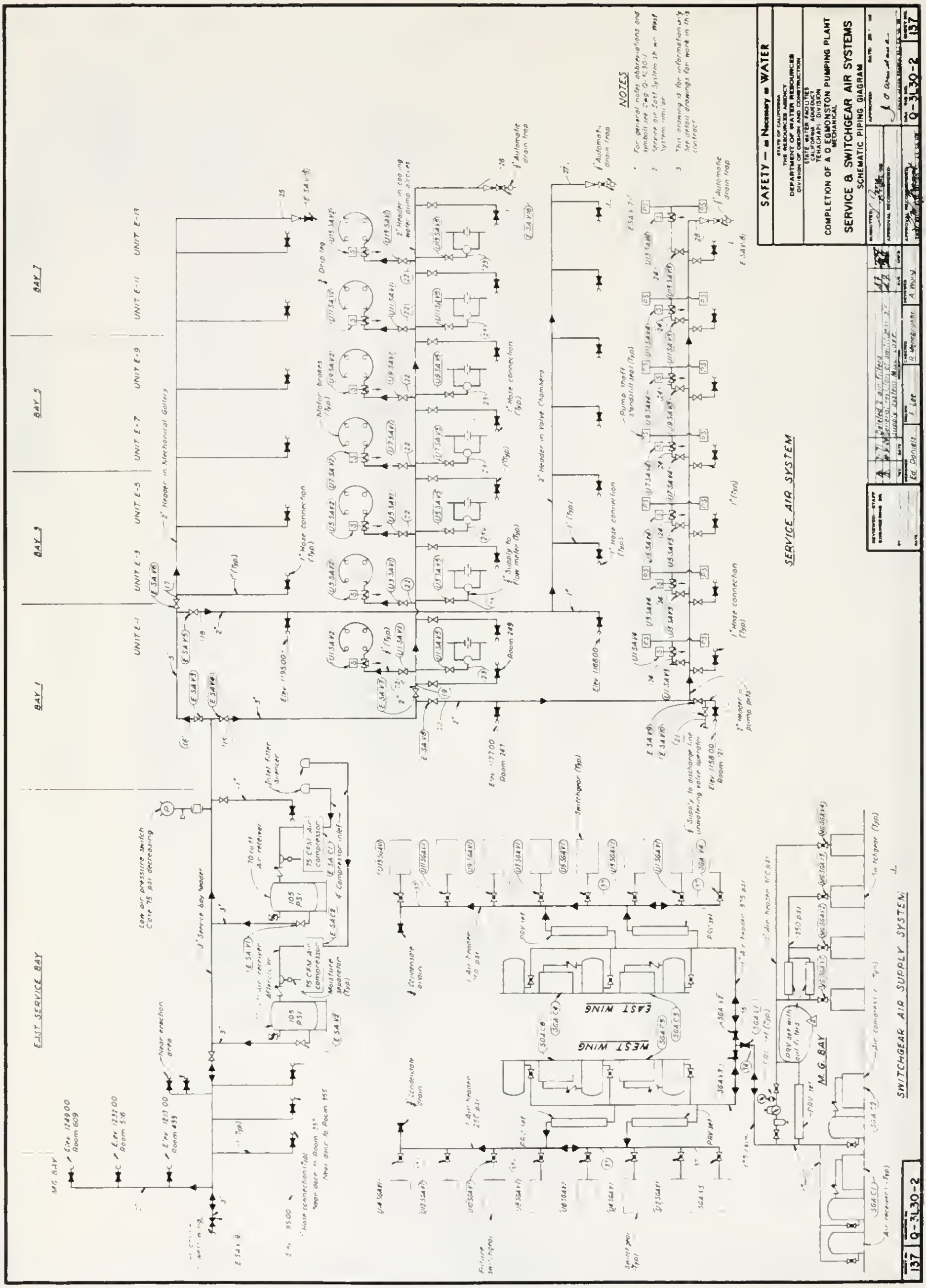

Figure 628. Service and Switchgear Air Systems

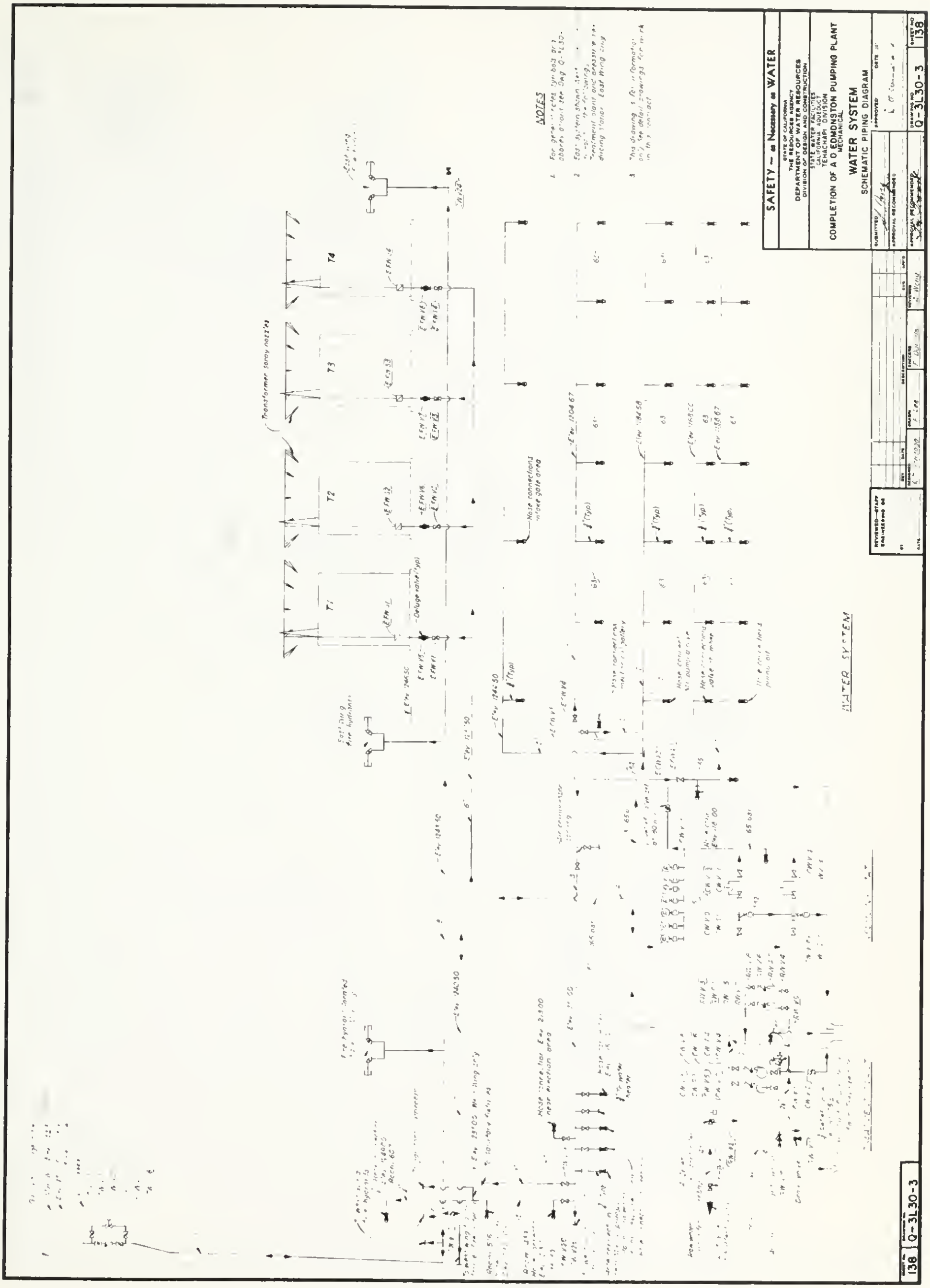

Figure 629. Water System

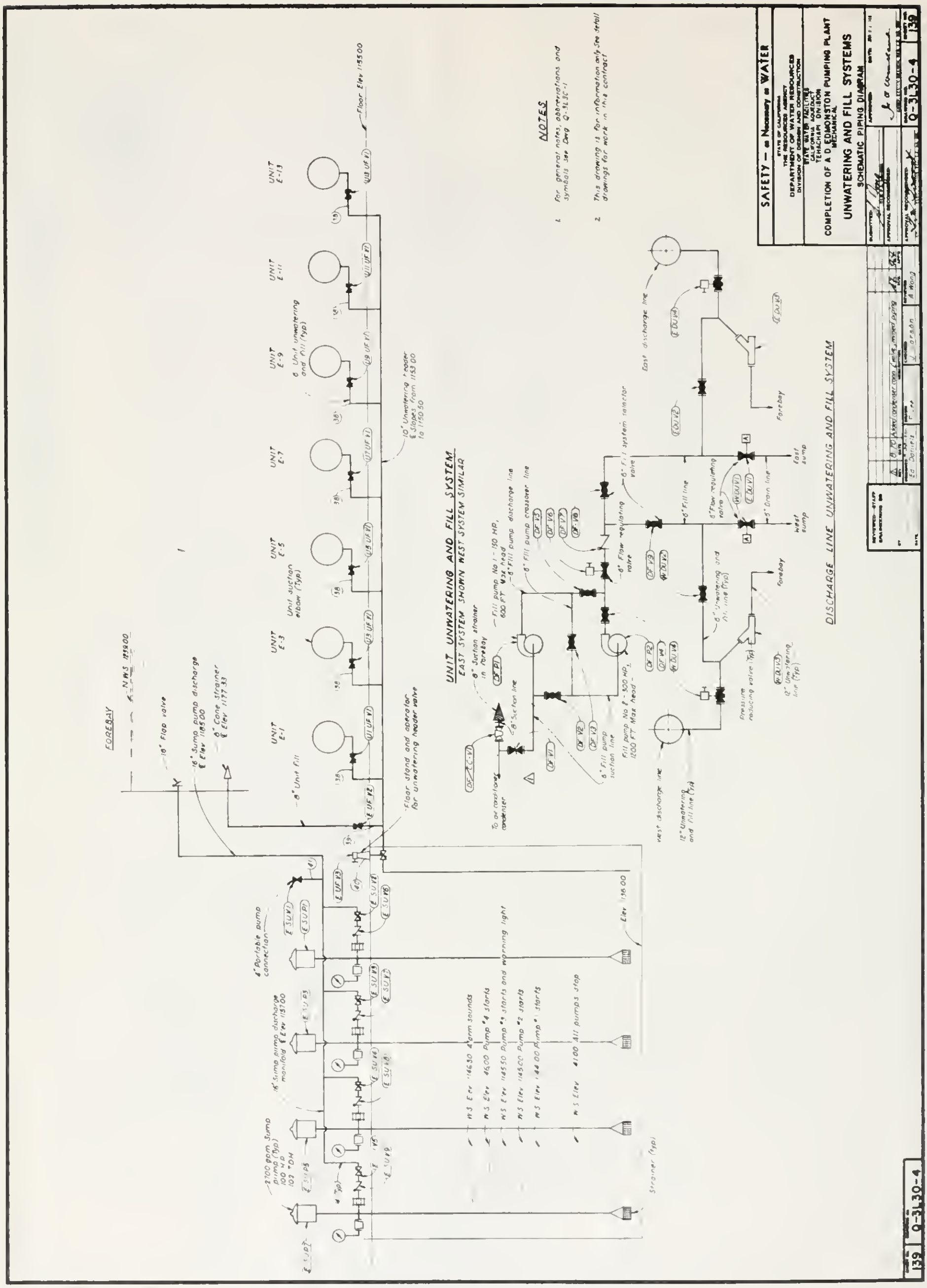

Figure 630. Dewatering and Fill Systems

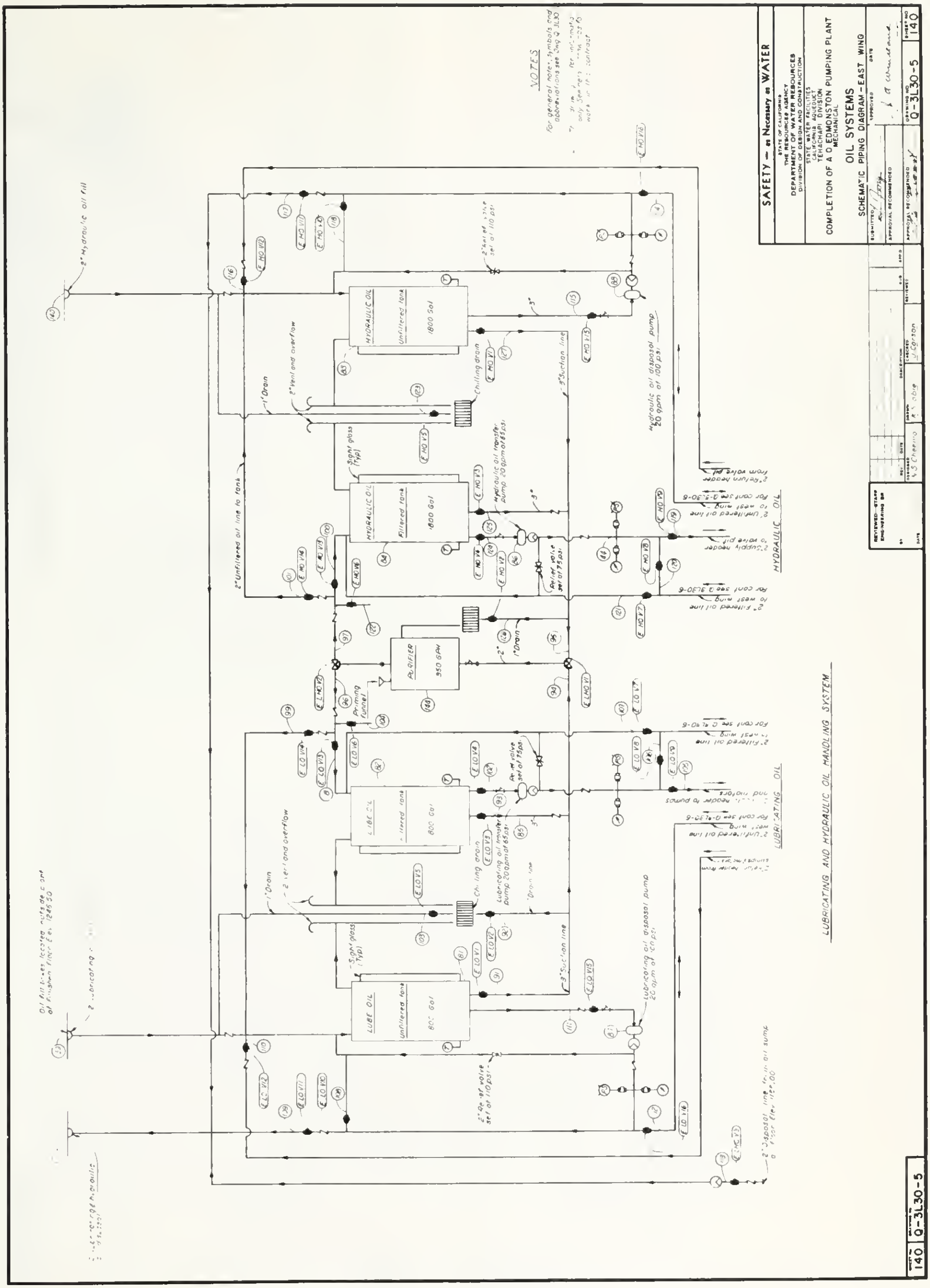

Figure 631. Oil Systems—East Wing

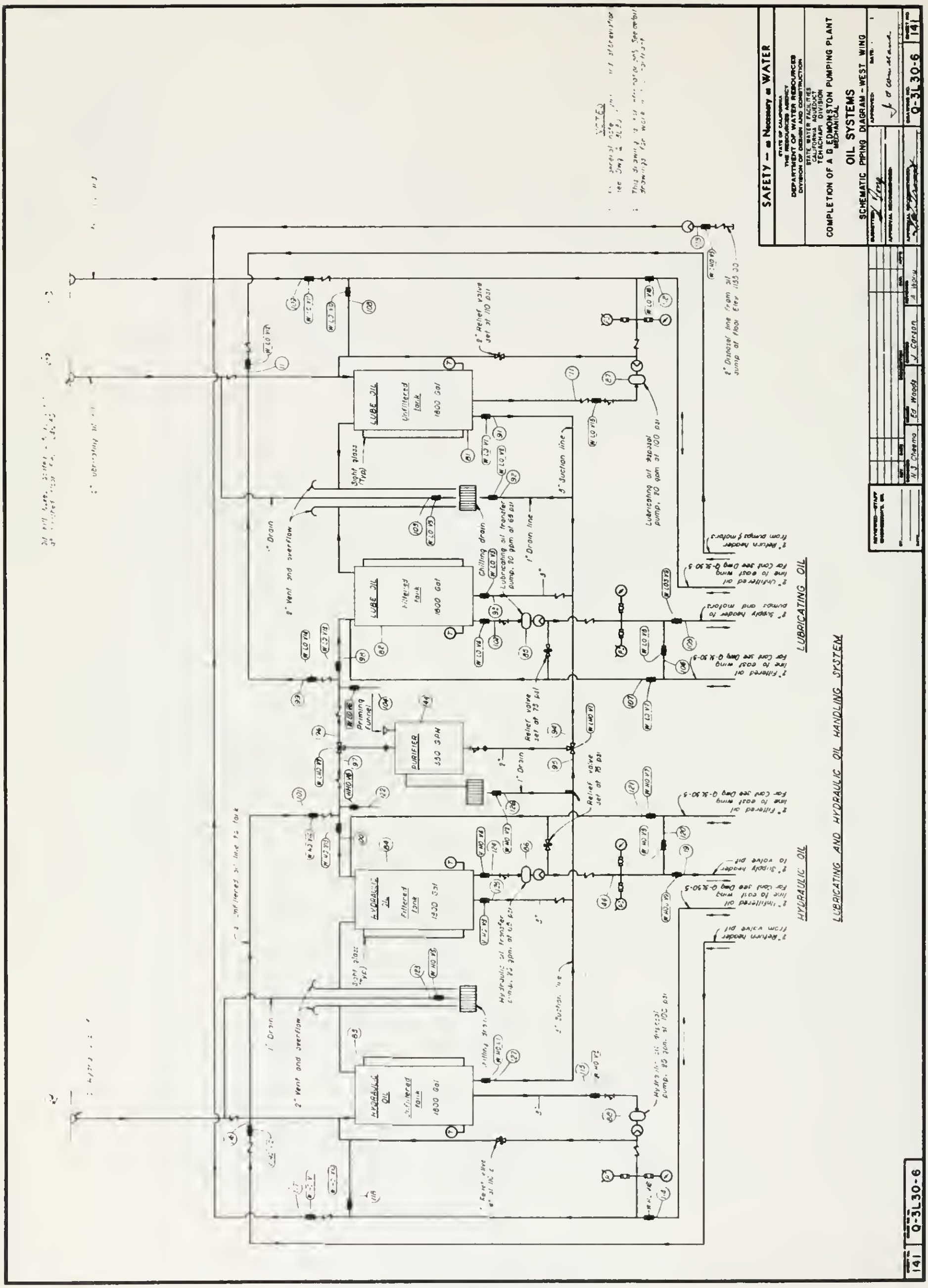

Figure 632. Oil Systems—West Wing

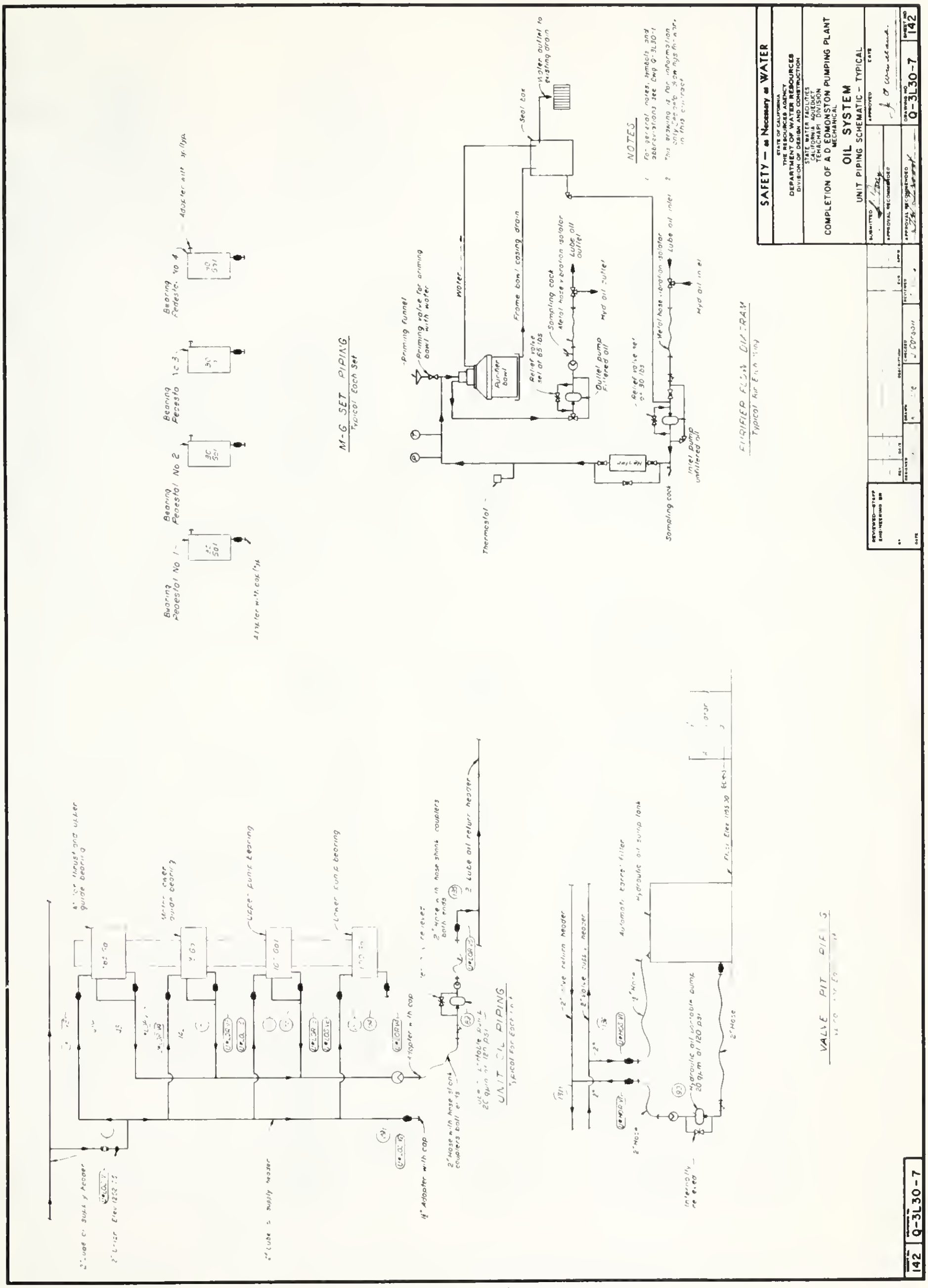

Figure 633. Unit Oil System

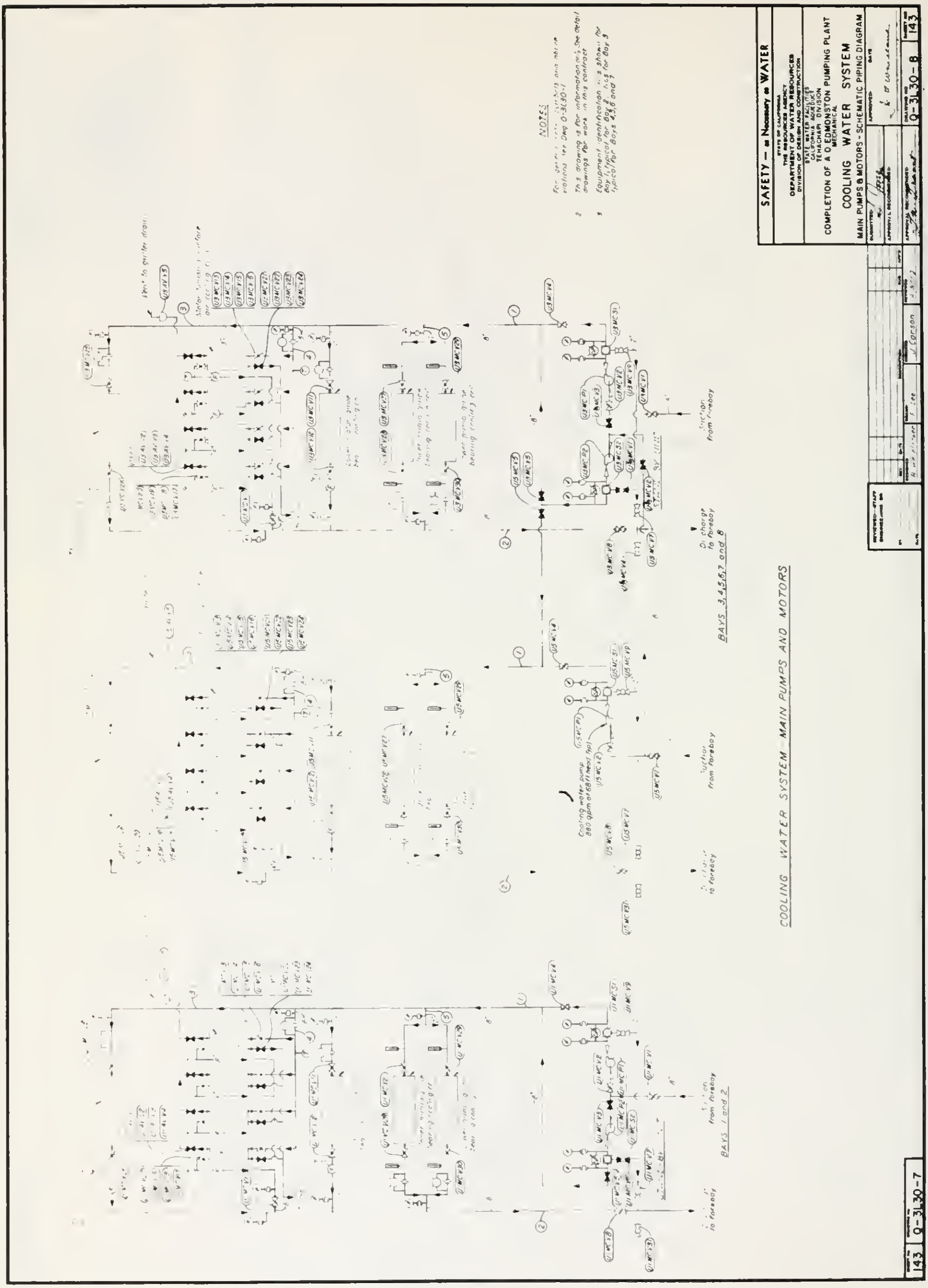

Figure 634. Cooling Water System—Main Pumps and Motors

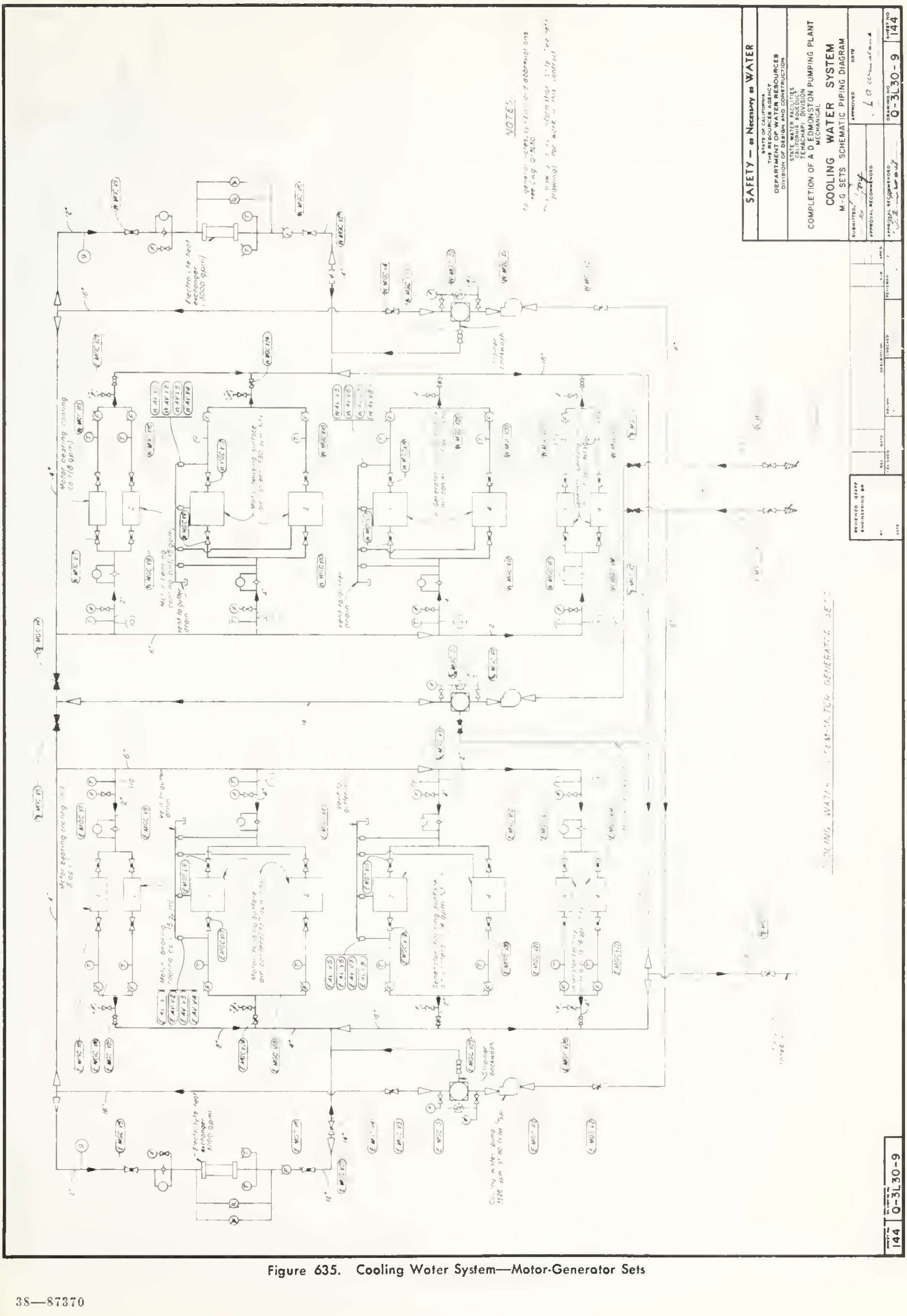

Figure 635. Cooling Water System—Motor-Generator Sets

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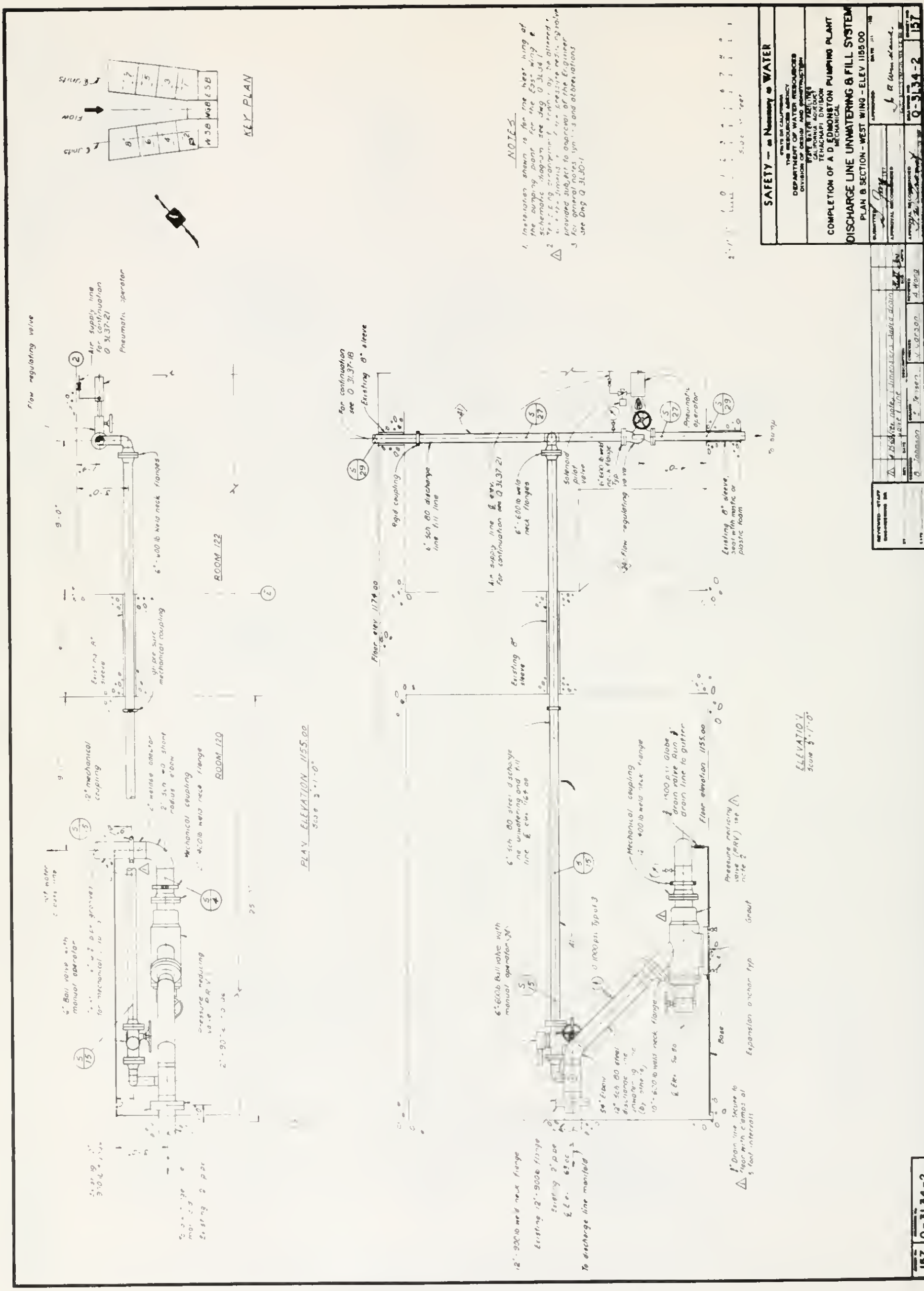

Figure 636. Discharge Line Dewatering and Fill System—West Wing

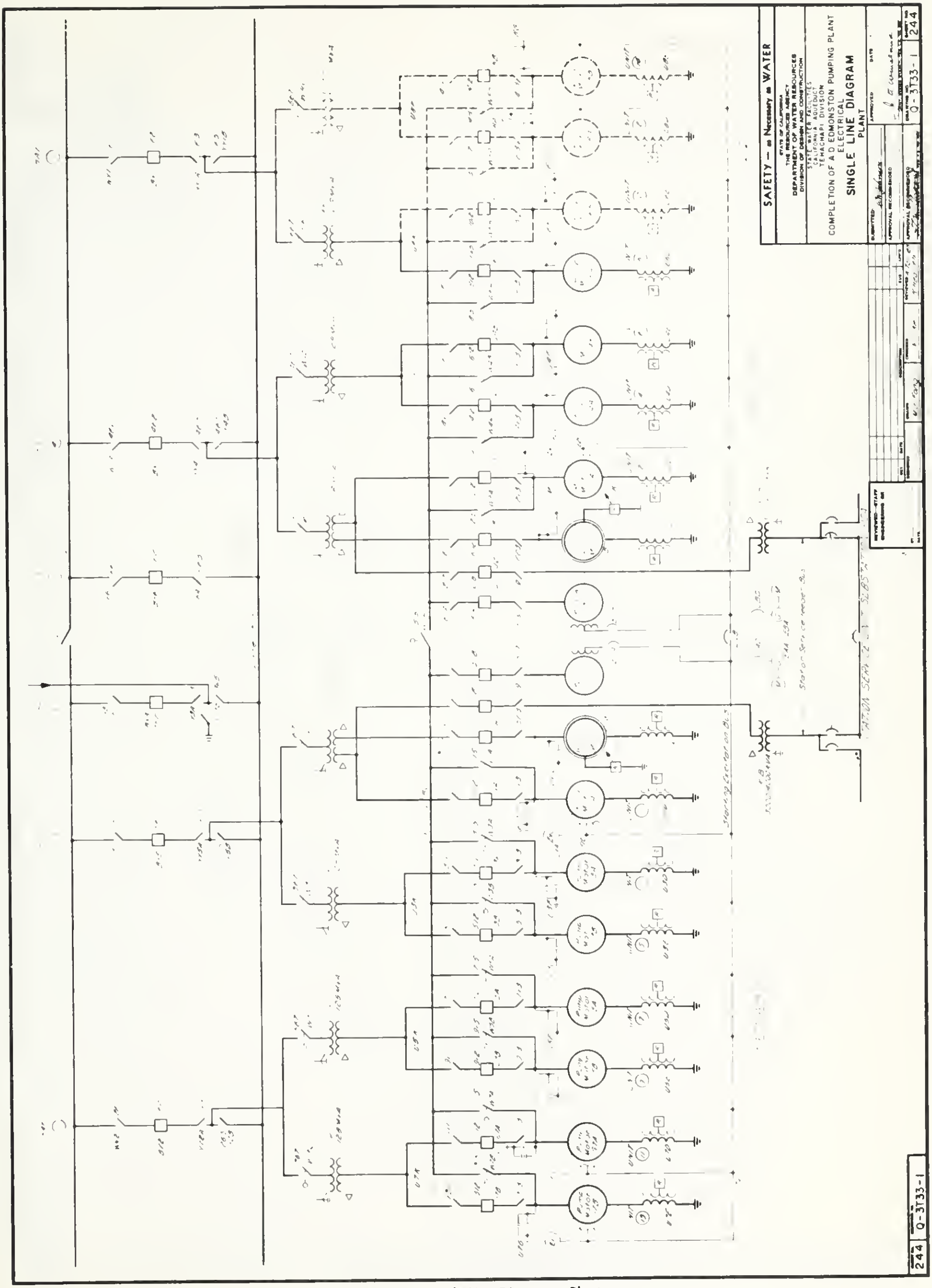

Figure 637. Single-Line Diagram—Plant

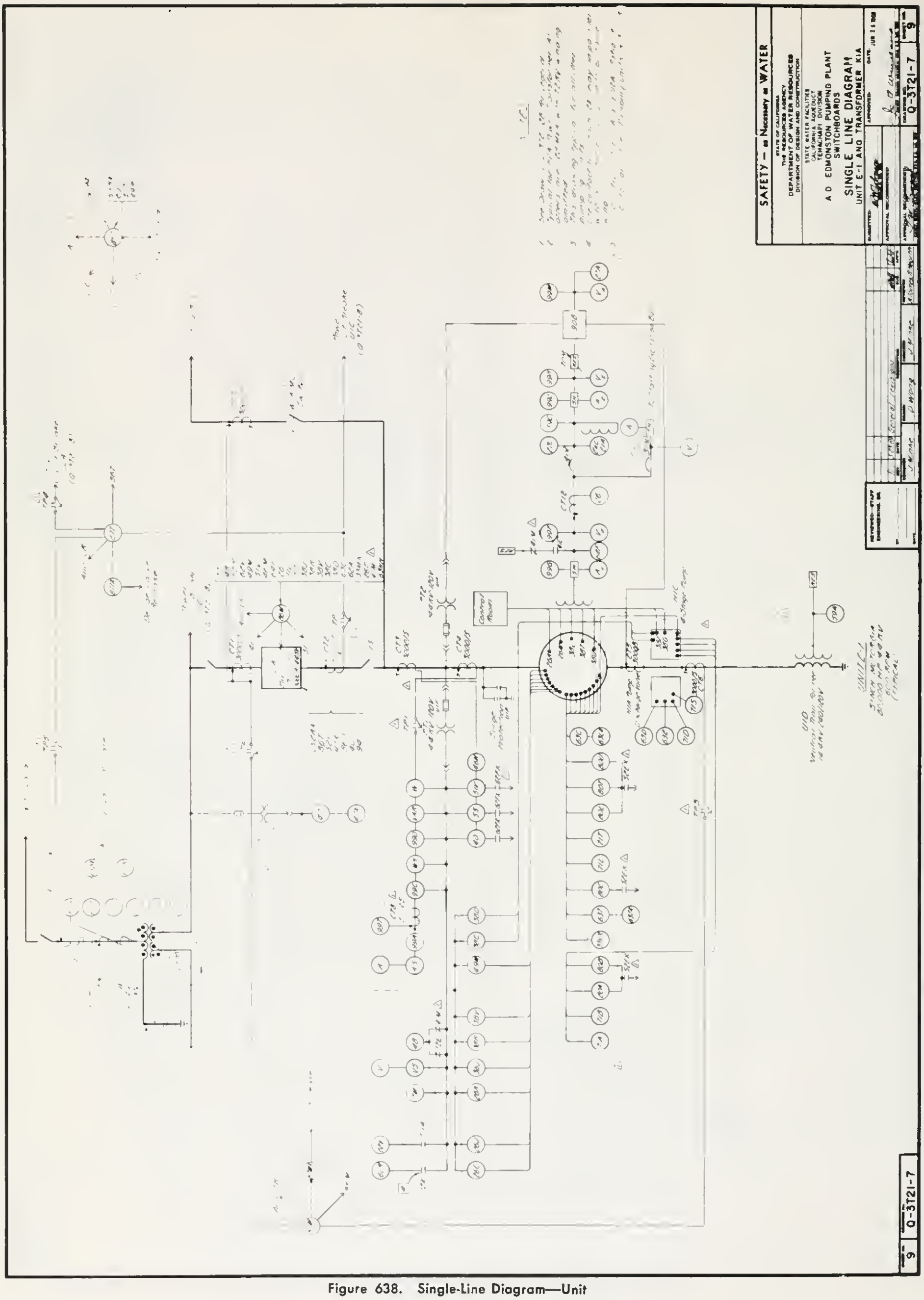

Figure 638. Single-Line Diagram—Unit

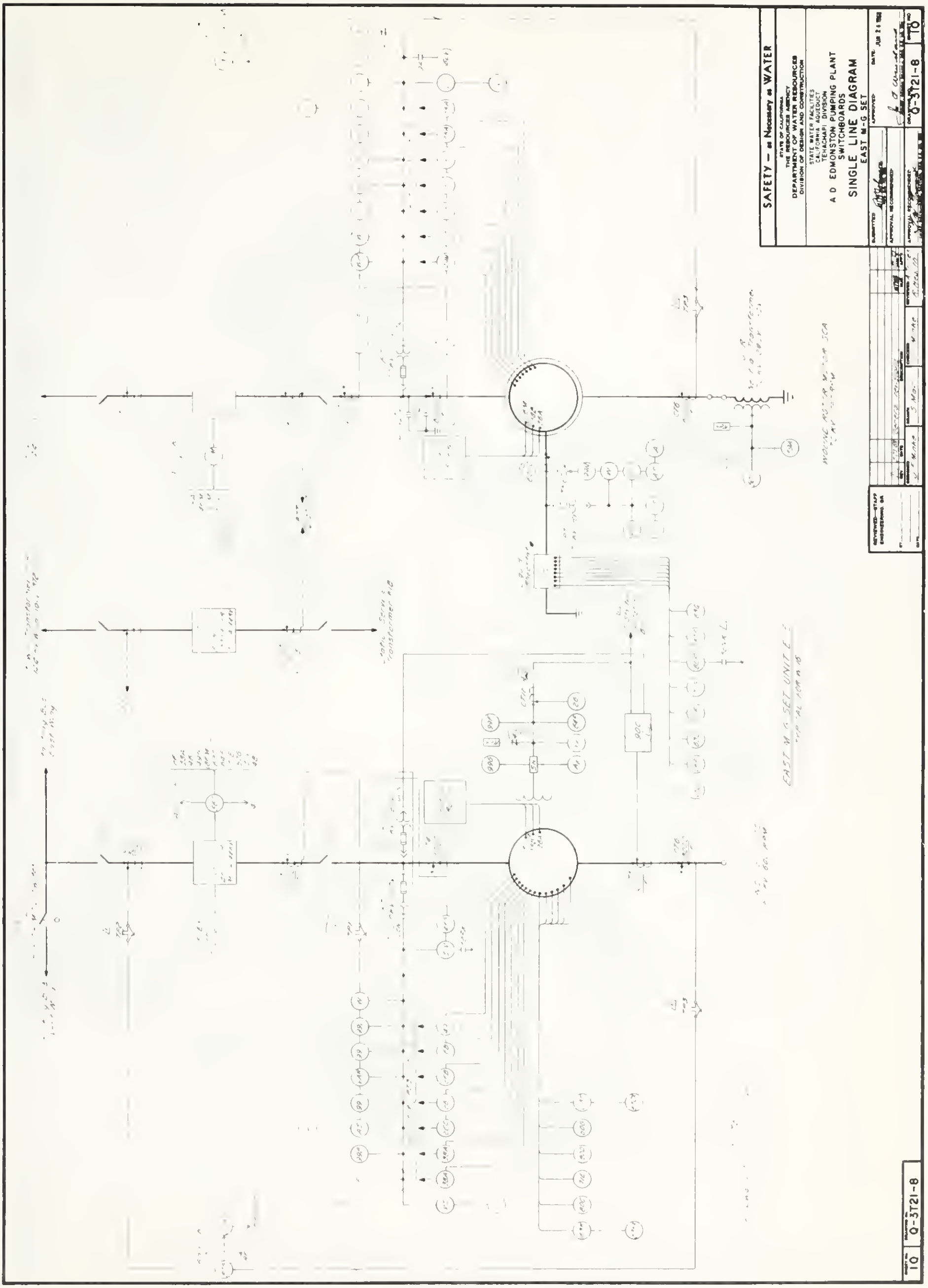

Figure 639. Single-Line Diagram—East Motor-Generotor Set

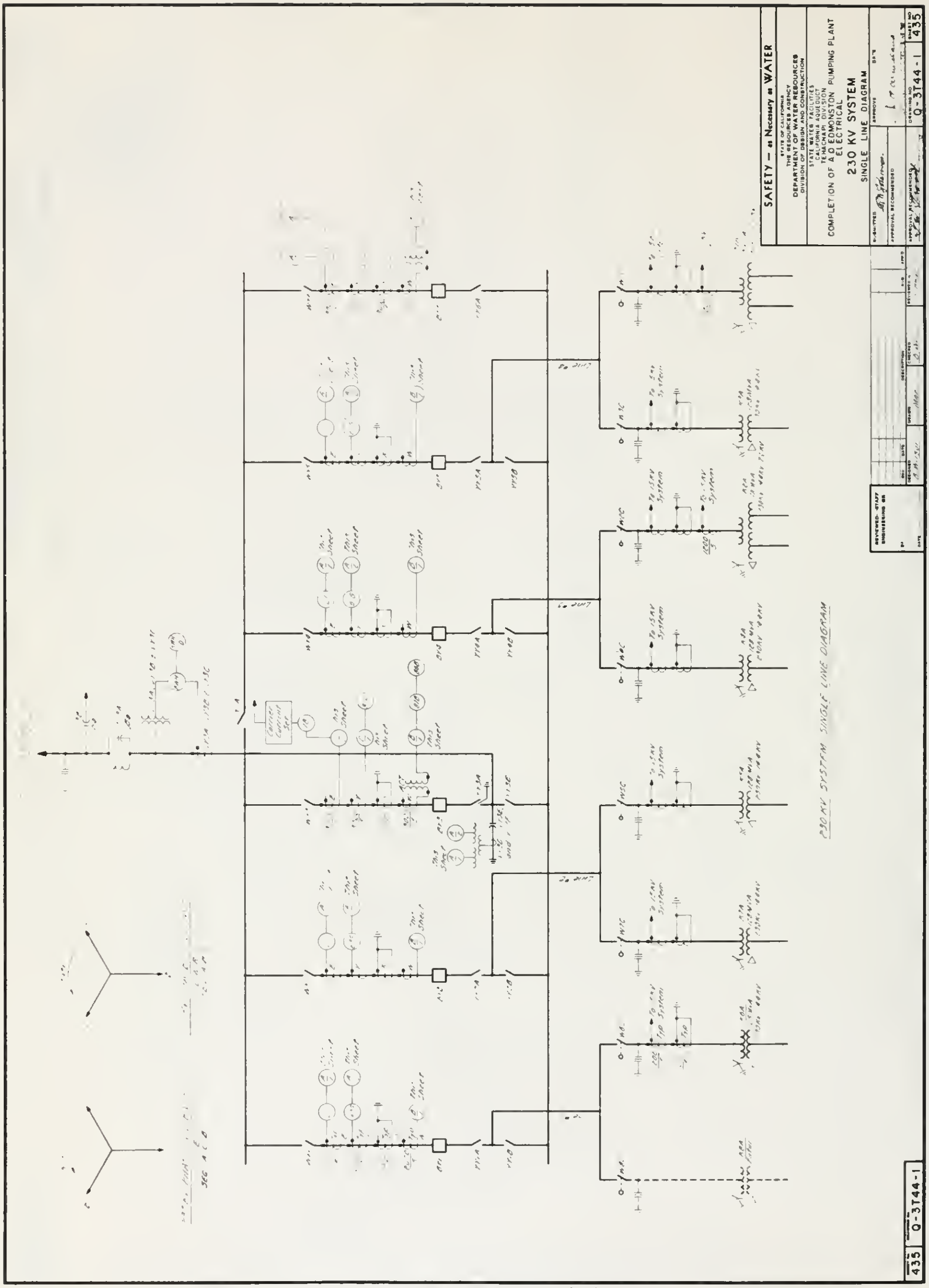

Figure 640. Single-Line Diagram—230-kV System

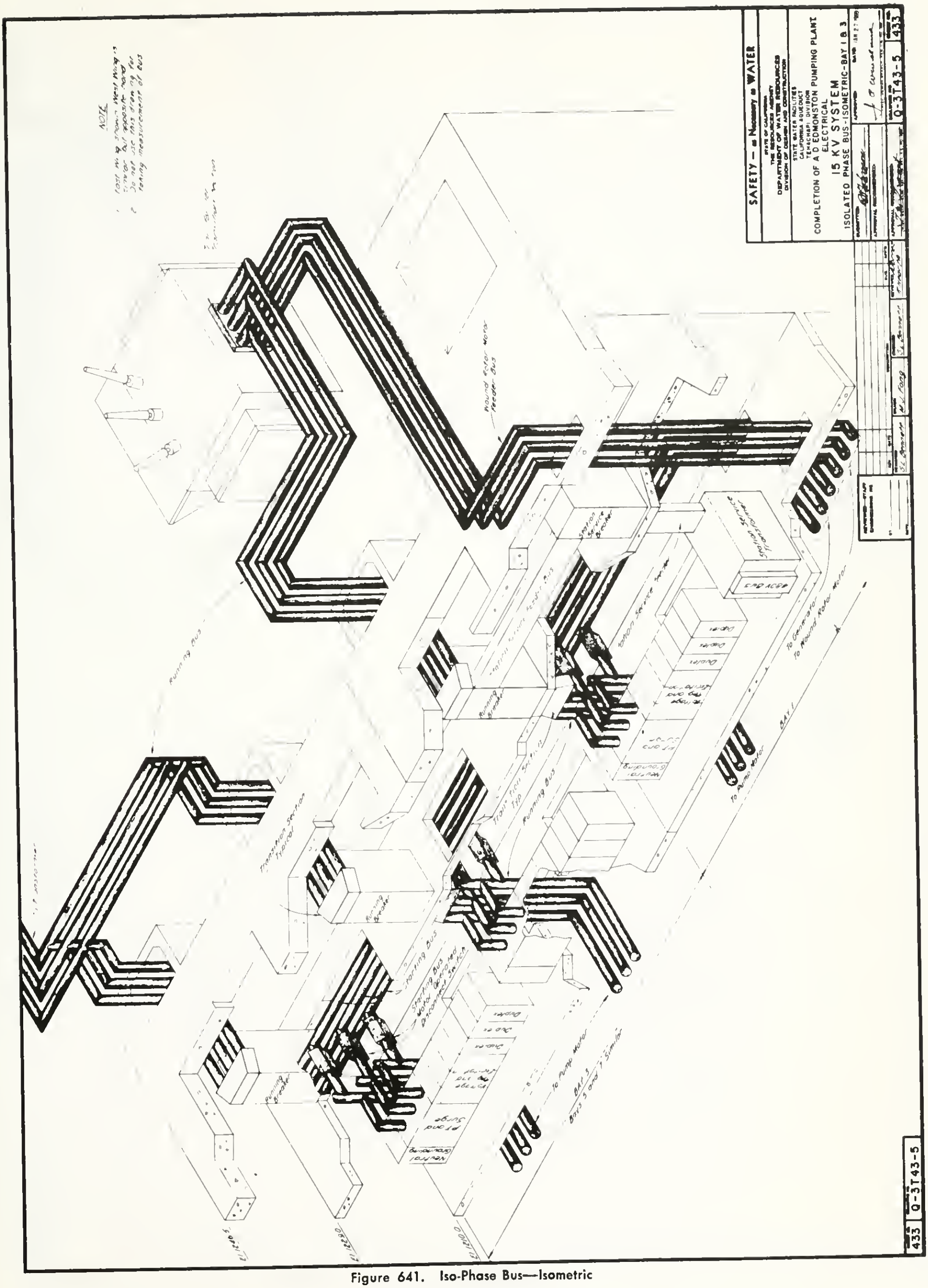

Figure 641. Iso-Phase Bus—Isometric

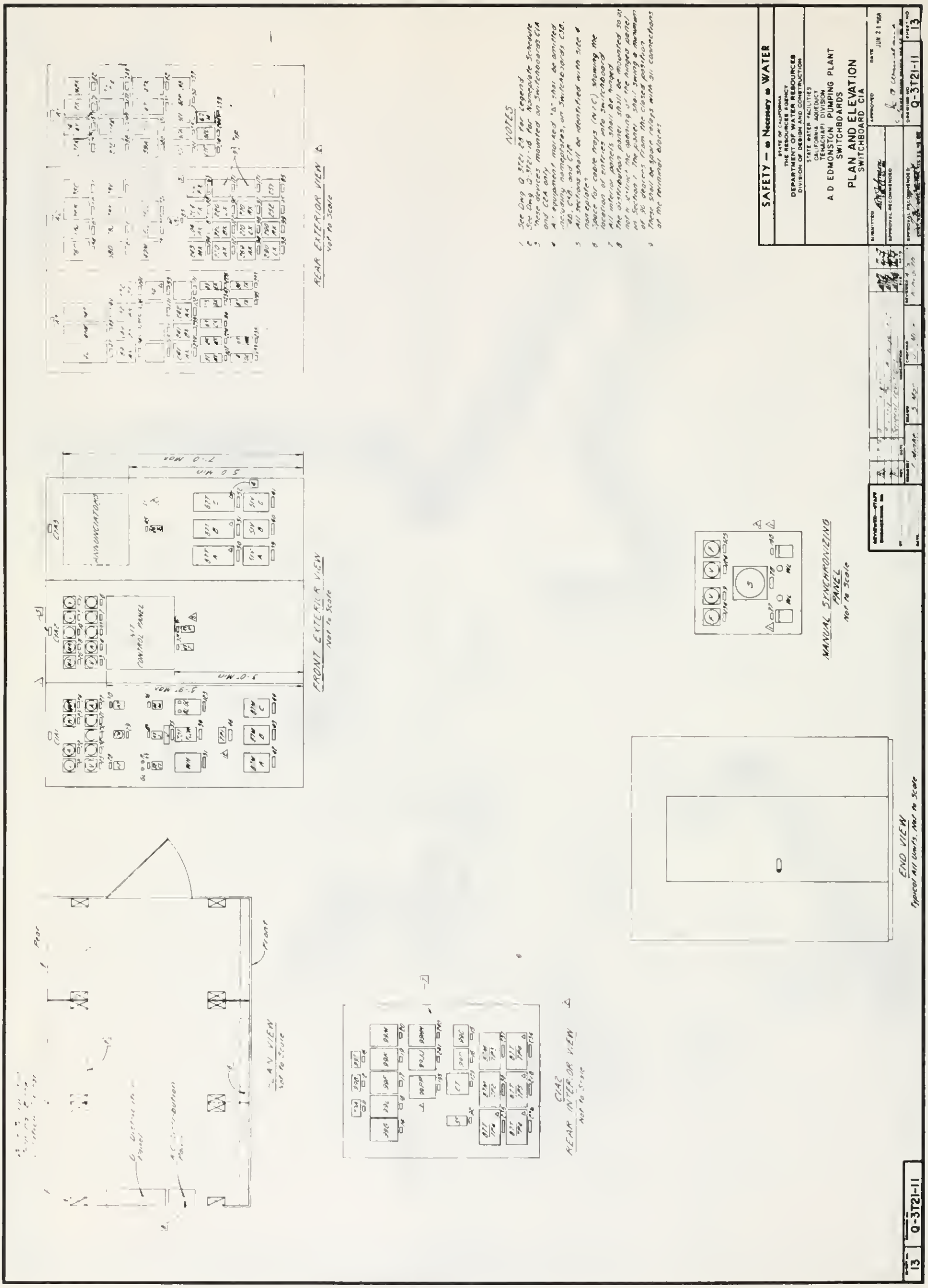

Figure 642. Switchboord

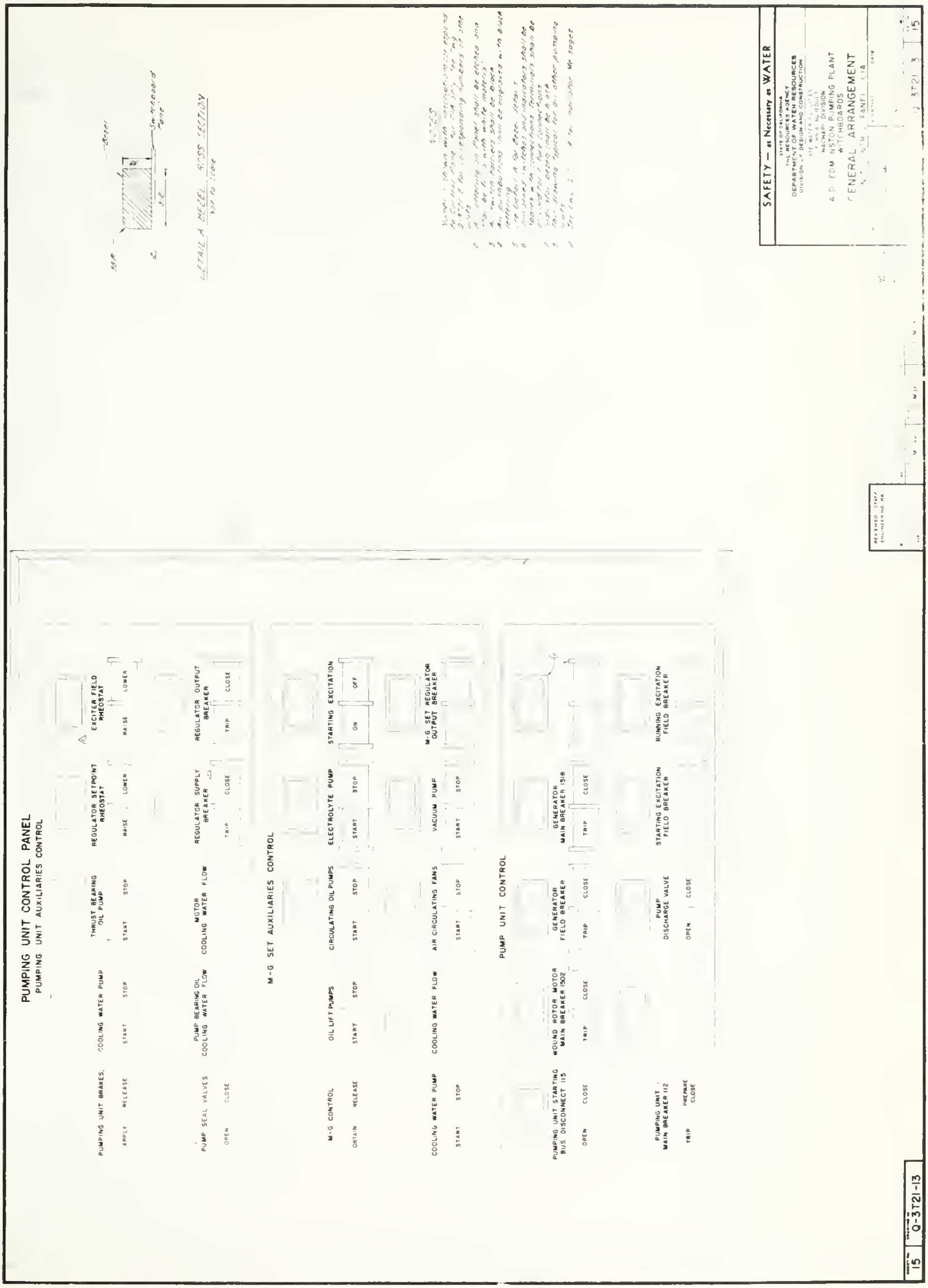

Figure 643. Unit Control Panel

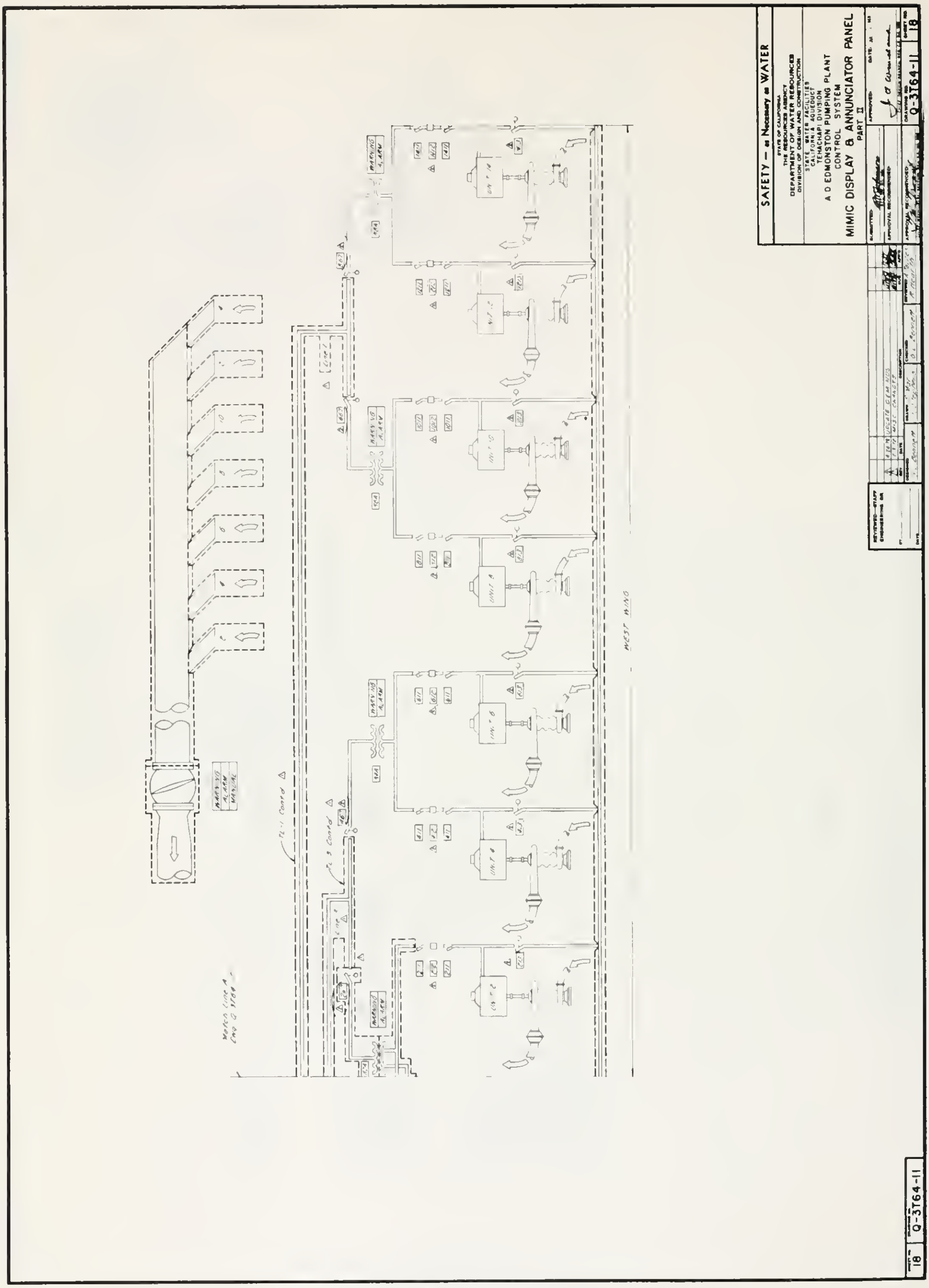

Figure 644. Mimic Display

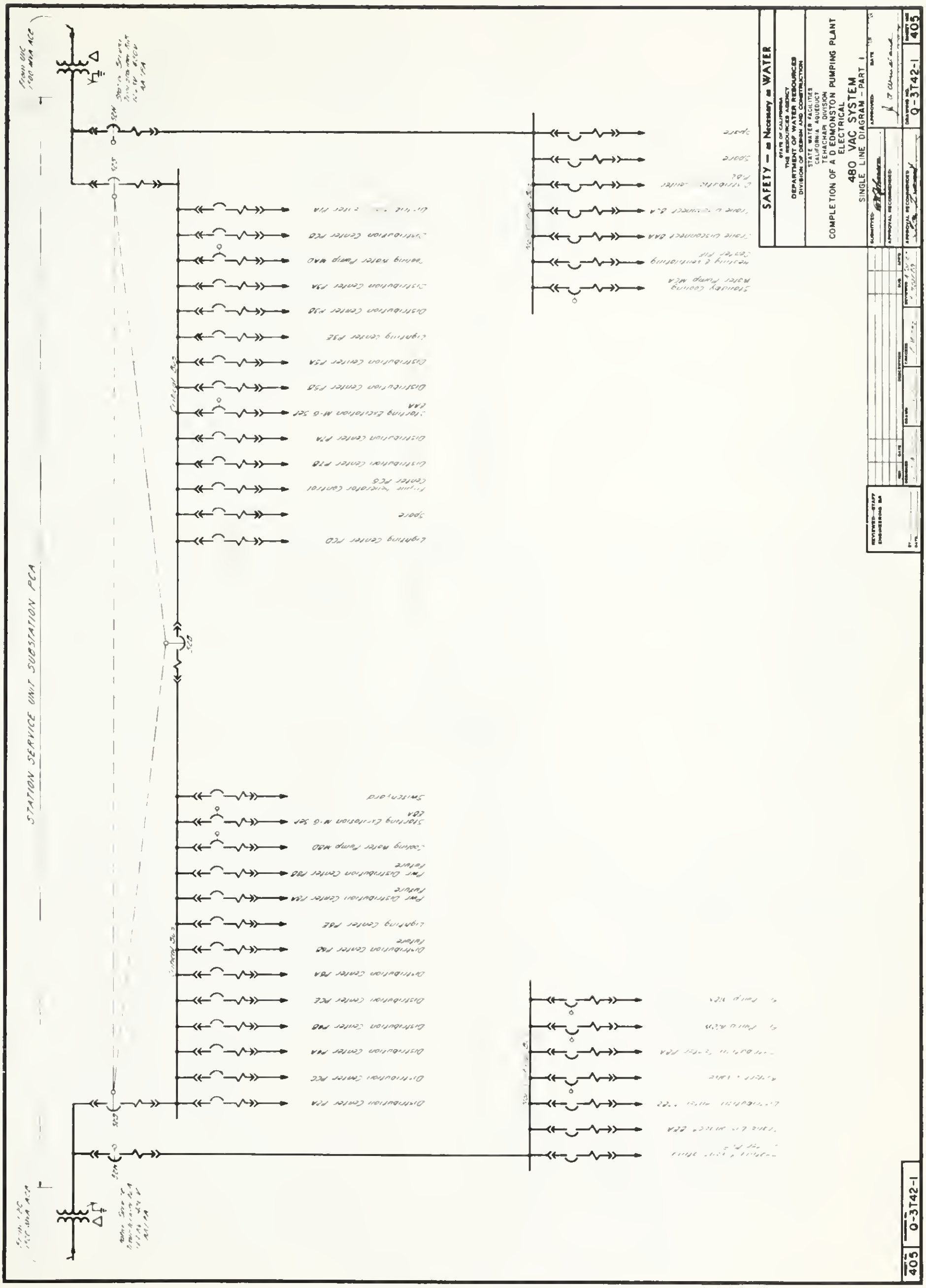

Figure 645. 480-VAC System

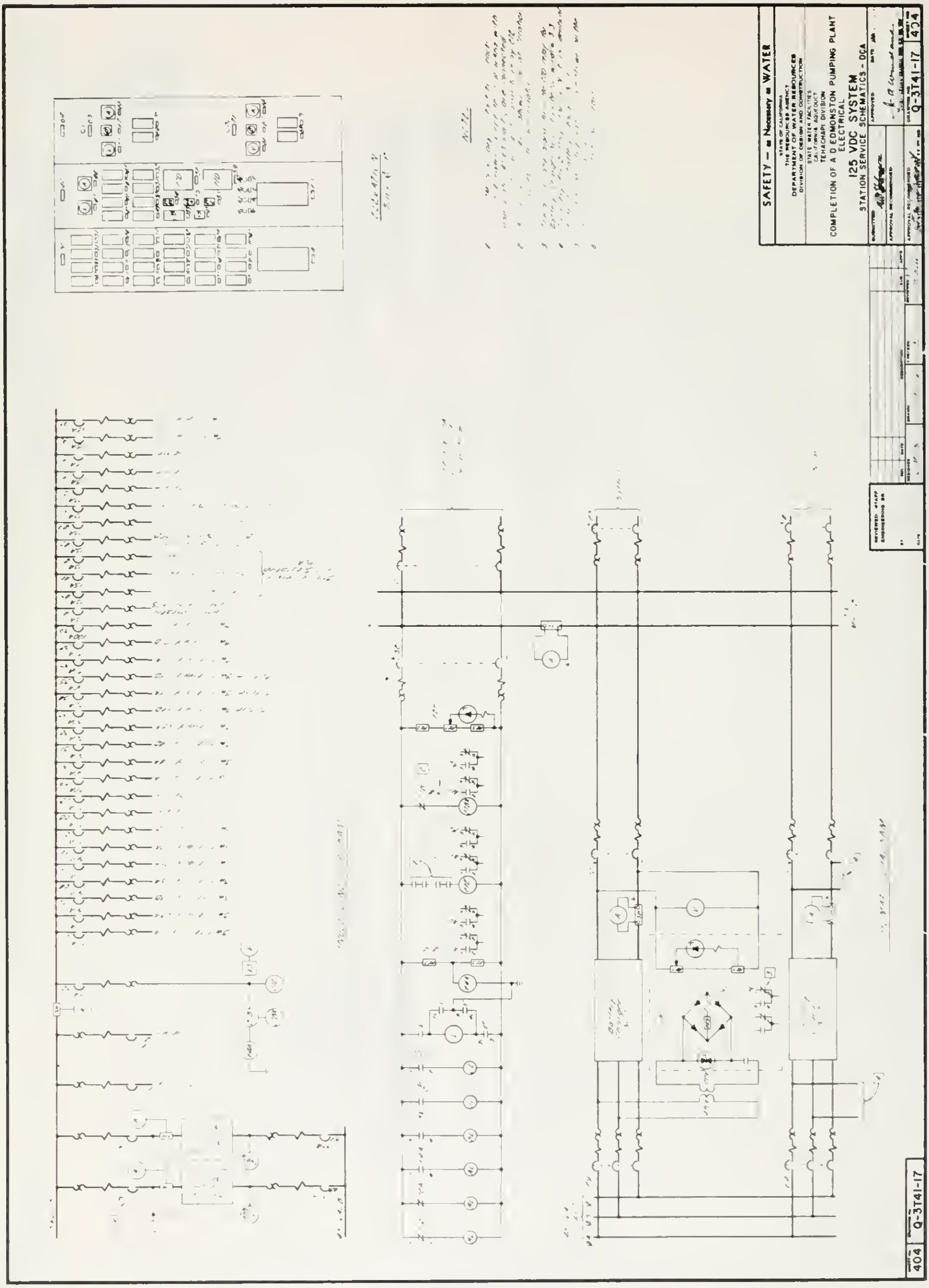

Figure 646. 125-VDC System

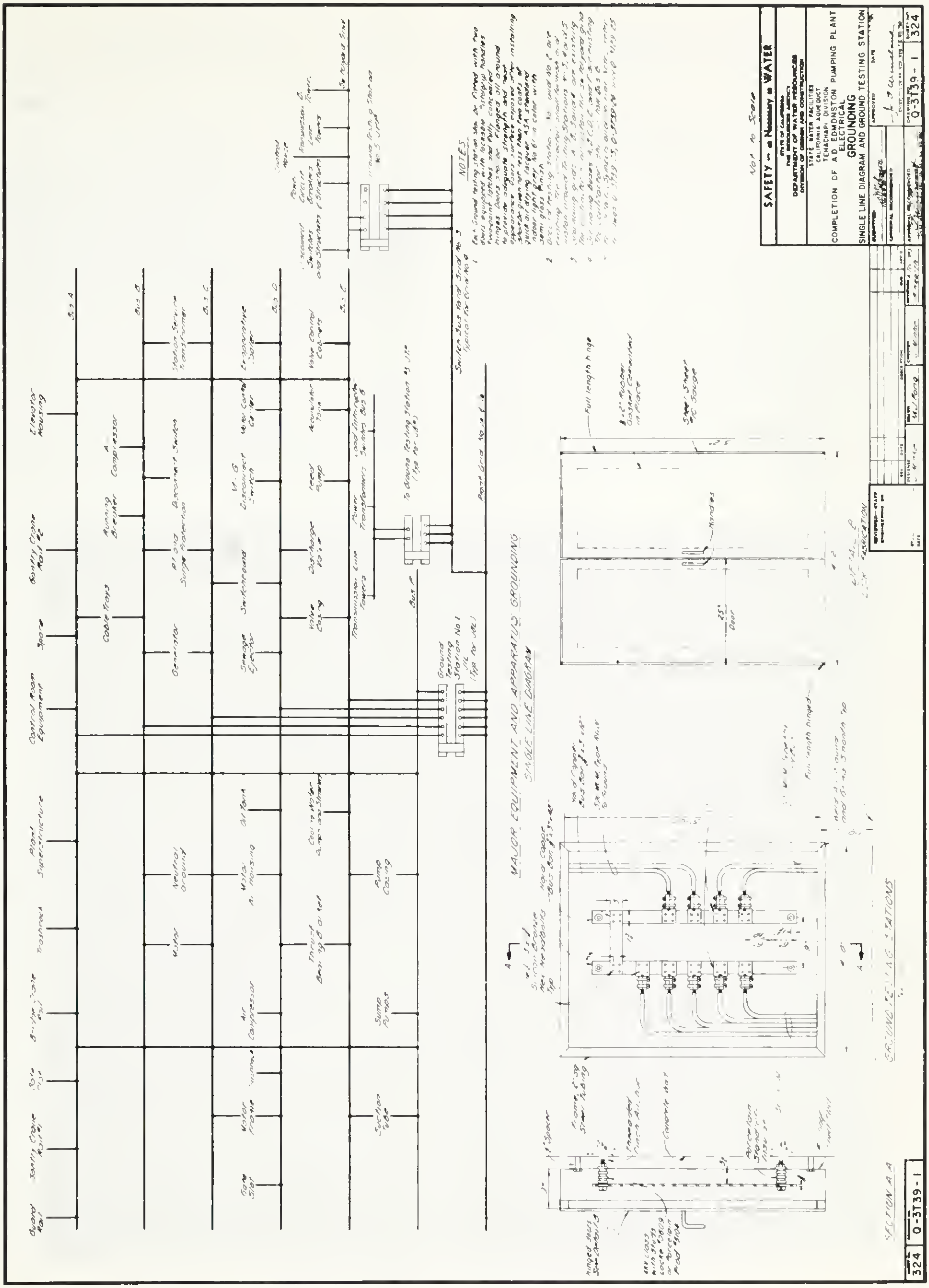

Figure 647. Grounding

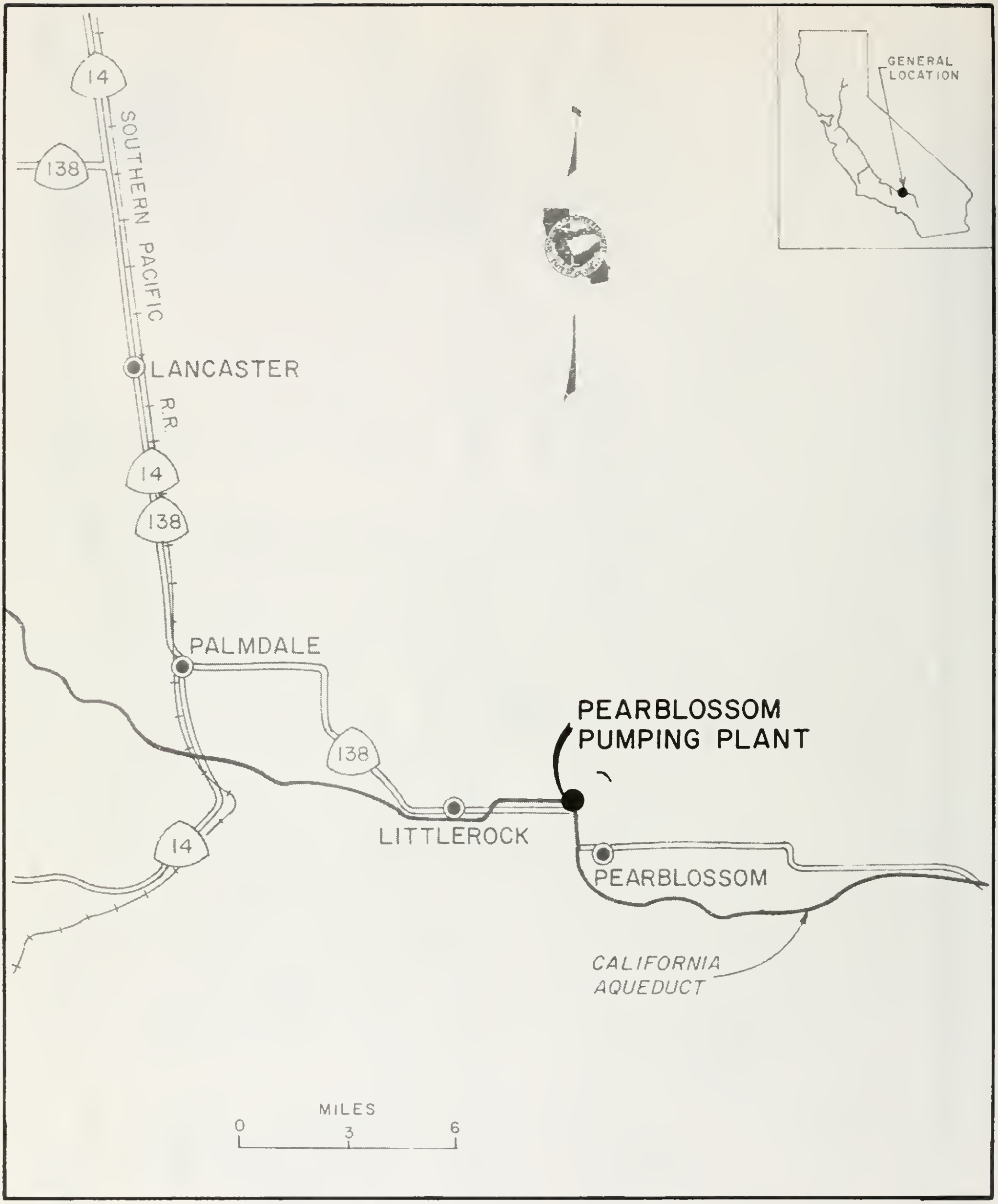

Figure 648. Location Map—Pearblossom Pumping Plant

CHAPTER XIV. PEARBLOSSOM PUMPING PLANT

General

Location

Pearblossom Pumping Plant is located near the community of Pearblossom in Los Angeles County approximately 25 miles from the City of Lancaster and 12 miles east of the town of Palmdale. The site is adjacent to North 116 Street East and north of State Highway 138, Pearblossom Highway (Figures 648 and 649).

Purpose

This is the southernmost pumping plant on the California Aqueduct. The water is lifted through a normal static head of 540 feet from the plant, then flows by gravity to Silverwood Lake, through the San Bernardino Mountains to Devil Canyon Powerplant, and finally on to Riverside County and Lake Perris, the terminal facility of the California Aqueduct.

Description

This plant, upon completion of second-phase developments currently under construction, will have six pumping units with a total capacity of 1,380 cubic feet per second (cfs). Four pumping units were installed in the first phase, which was completed in 1973 (Figures 650 and 651). The units are vertical-shaft, single-stage, centrifugal pumps directly connected to vertical synchronous motors. Four pumping units have a capacity of 276 cfs each and are powered by 22,500-horsepower motors. The remaining two units have a capacity of 138 cfs each and 11,600-horsepower motors.

Figure 649. Aerial View—Pearblossom Pumping Plant

Figure 650. Pearblossom Pumping Plant

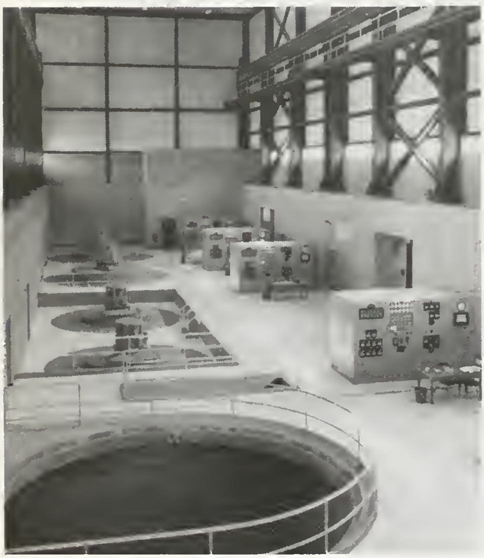

Figure 651. Interior View at Motor Floor

The 276-cfs units discharge through 42-inch spherical valves, and the 138-cfs units discharge through 30-inch spherical valves.

There are two manifolds and two discharge lines. Two large pumping units and one small unit are connected to each manifold. Each manifold connects to a 9-foot-diameter discharge pipe approximately 6,300 feet in length.

Plans call for a future extension of the plant structure which will increase the plant capacity by 700 cfs. A third discharge pipe will connect the new pumping units to the existing third bay of the siphon outlet structure.

Representative drawings are included at the end of this chapter.

Geology

Areal Geology

The plant site is near the southern edge of the broad, alluvial-filled, Antelope Valley. The site area is an alluvial fan which overlies an irregular granitic bedrock surface. The San Andreas rift zone is approximately $2\frac{1}{2}$ miles south of the site, creating topography characterized by low hills and depressions. Three geologic units dominate the area, Recent and Older alluvium overlying the Holcomb Ridge quartz monzonite.

The plant foundation is the Holcomb Ridge quartz monzonite, a deeply weathered to fresh, intensely fractured, granitic rock. This granitic bedrock contains numerous veins and dikes of aplite and pegmatite.

Older alluvium is a compact, cohesive, reddish-brown, arkosic silty sand with a trace of gravel and cobbles. Thickness of the Older alluvium near the plant site ranges from 0 to 30 feet. Recent alluvium is loose, light gray, gravelly sands interbedded with compact, reddish-brown, silty sand. Thickness of the Recent alluvium near the plant site ranges from 9 to 45 feet.

North and west of the plant site, alluvium is very thin in contrast to the rest of the area. The Older alluvium is missing and may never have been deposited in this area. Depth to the granitic bedrock within the excavation area is approximately 60 feet.

Site Geology

The plant foundation is Holcomb Ridge quartz monzonite. Numerous faults and a well-defined joint system are present in this fractured granitic formation. Design of the structure was influenced by deep weathering along the joint system and by the presence of large amounts of expansive clays, a product of hydrothermal alteration of the feldspars.

Intersecting joints and faults caused some of the steeper slopes to become unstable, resulting in these slopes being laid back. Some of the more deeply weathered and fractured joints were overexcavated and backfilled with concrete or compacted backfill.

During excavation of the discharge lines, a number of vertical to steeply dipping faults and shears were exposed, varying from 12 inches to 25 feet in width. The fault system within this area crosses the discharge lines roughly subparallel to the San Andreas fault zone. Although numerous faults are present in the foundation rock of the plant and discharge lines, they are not considered active, but a major quake along the San Andreas zone could cause some movement.

Ground water was not a major problem. The flows were small and drains were needed only in the service bay area.

Geologic Exploration

Thirty-eight rotary drill holes were employed for exploring the intake channel, spill basin, and pumping plant bowl. Three of the holes were drilled for rebound gauges and three for the installation of slope-indicator casing. A dragline trench was excavated to a depth of approximately 50 feet in the bowl. Geophysical exploration consisted of gravity and seismic refraction surveys and electric logging of 12 drill holes.

Instrumentation

Prior to the initial site development, three slope-indicator gauges and three rebound gauges were installed at the plant site. The slope indicators were monitored throughout construction with no significant movement indicated. Of the three rebound gauges, one was of the continuous reading type and was monitored as the site excavation proceeded. The other two were buried at grade elevation and recovered when excavation was completed. The maximum rebound recorded for the site development was 0.11 of a foot.

Seismicity

The seismically active east-west trending San Andreas fault zone is 2½ miles south of the plant site. The San Jacinto fault, considered to be the most active in Southern California, branches southerly from the San Andreas fault approximately 5 miles southwest of the plant. Branch faults extend from these major zones through the plant area. It is probable that earth movement will occur during the life of the plant. A major earthquake occurred February 27, 1969, with the epicenter near Palmdale, 13 miles from the plant.

Civil Features

Preliminary Studies

Preliminary studies for Pearblossom Pumping Plant included the following:

1. Plant structure with its civil, electrical, and mechanical features.
2. Pump discharge lines with manifolds and siphon outlets.
3. Pumping pool.
4. Electrical switchyard.
5. Site development consisting of bowl excavation for the plant and approach canal, access roads, and drainage.

Location studies were made which considered different sites with surface and buried discharge lines. In addition to optimization, another objective of the preliminary studies was to provide information essential for the design of adjacent project features. The overall plant dimensions were required to size the plant bowl excavation. This involved principally the determination of the size and number of pumping units and adequate space requirements for necessary mechanical and electrical equipment and allowance for future expansion.

Site Development

Major features of site development were:

1. Bowl excavation for the plant site and intake canal.
2. Excavation and compacted embankment for the spill basin.
3. Access roads and drainage.

Average depth of the bowl excavation is about 75 feet. Bowl dimensions in the east-west direction are

452 feet at the bottom and 800 feet at the top. In the north-south direction along the intake, the excavation is approximately 4,000 feet long. Cut slopes are 2:1 with 20-foot-wide benches at 25- to 30-foot vertical intervals.

The spill basin is 15 feet deep, 910 feet long, and 720 feet wide, and the side slopes are 2:1. It is not being utilized in the current operation of the California Aqueduct. However, under ultimate development, it will provide storage for up to one hour's flow of aqueduct water in the event of flow mismatches or power outage.

Runoff from the surrounding area is prevented from entering the plant bowl by a protective dike on the south, a drainage ditch on the east, and a cutoff ditch on the west. Storm water entering the bowl is collected in ditches and routed through slope drains into the intake channel.

Plant Structure

Pearblossom Pumping Plant has three pump bays (two pumps per bay) and a service bay. Each bay is a structurally independent monolith separated by expansion joints. The plant is 275 feet - 6 inches long; the substructure and superstructure are 130 feet and 55 feet - 6 inches wide, respectively. The height from centerline of units to the motor floor is 24 feet and from the motor floor to the top of the crane rail 45.5 feet. The general shape of the lower portion of the substructure for the pump bays was governed by the geometry of the 135-degree suction tube. Size of pump bays and service bay was based on space requirements of pumps, motors, and auxiliary equipment.

The plant is located on the westerly side of the bowl to permit future expansion on the east side without enlarging the bowl excavation. The substructure and west wall have shear keys, embedded waterstops, and knockout panels designed for future extension.

The plant is founded on granitic rock of variable soundness but generally more than adequate for the plant foundation loading. To control air slaking of the foundation rock, all load bearing surfaces were coated with a 2-inch layer of wet mix shotcrete as soon as excavation reached the required elevation. Slopes for the foundation excavation varied from ¼:1 to 6:1. The depth of cut varied, with the maximum at the dewatering sump in the service bay, which was 81 feet below the bottom of the bowl. During normal operations of the plant, foundation loadings range from 3,500 to 7,800 pounds per square foot.

Waterways

Intake Facilities. Intake facilities include a channel transition, suction tubes, trashracks, and bulkhead gates.

The channel transition is 251 feet long with a 16-foot bottom width at the upstream end and a 189-foot - 6-inch bottom width at the face of the plant structure. The transition is approximately 15 feet deep with 2:1 side slopes and is completely lined with concrete.

Steel trashracks were installed at the upstream face of the plant. They were assembled in panels with vertical bars spaced to provide 3-inch clear spaces. They are cleaned by a mechanical rake which is operated by a 10-ton gantry crane that traverses the full length of the pumping plant deck at elevation 2,944 feet.

Six structural-steel bulkhead gates are available to permit dewatering of the suction tubes. When required, they are lowered into vertical slots just downstream from the trashracks by a 10-ton gantry crane. Unlike most other State Water Project plants, they are stored in individual slots just downstream from the operating position slots.

The suction elbows bend at 135 degrees to meet the invert of the shallow forebay. This bend also shapes the plant base into a wedge that is keyed into the foundation, thus providing adequate stability against horizontal sliding.

The suction elbows are part concrete- and part steel-lined. The liners are fabricated from welded steel plates and are embedded in the concrete substructure of the plant. A dewatering outlet is provided at the low point of each tube.

Pump Discharge Lines. Six Pearblossom pumps lift water in the California Aqueduct through the discharge lines. There are two parallel discharge lines in this sytem. Flow from Pumps Nos. 1, 2, and 3 is combined by a manifold into the westerly discharge line, which is a buried pipeline. A similar manifold combines flow from Pumps Nos. 4, 5, and 6 into the east discharge line. From pump to outlet, the length of this discharge system is 6,790 feet.

Each of the pump discharge lines was designed to deliver a flow of 690 cfs to the single siphon outlet structure with a friction head loss of 17.6 feet. The design pressure head at the plant is 767 feet, which includes an allowance for hydraulic transients. Two 29-foot-diameter air chambers furnish surge control during transient conditions and effectively reduce water-hammer pressures.

All of the discharge lines are buried in the granular soil, except those inside the plant and at the air chamber. In addition to simplicity of installation, buried pipes are easy to anchor, minimize right-of-way problems, and provide relatively simple maintenance and drainage conditions.

Many features of these discharge lines have been designed according to criteria developed for the other aqueduct pumping plants and are described in Chapter 1 of this volume. Prominent in these criteria is articulation. All discharge lines at this plant have joints which will allow significant deflection of the pipe segments before any leakage can occur.

There are five characteristic parts to the pump discharge lines: manifolds; air chambers; buried steel pipes; prestressed-concrete cylinder pipes; and the siphon outlet.

Manifolds. The manifolds extend from the pump discharge valves to the air-chamber connections and include the valve tapers, articulation sections, wye branches, and concrete encasement (Figure 652).

Various pipe diameters are used in the manifolds to maintain flow velocity at 12.5 feet per second (fps). Piping intersection angles at wye branches are 60 degrees. All manifold piping is encased in concrete for anchorage and to resist external loads imposed by the deep backfill.

Air Chambers. Spherical air chambers furnish a dampening action to reduce fluctuations of hydraulic transients in the 6,790-foot-long discharge lines. They are connected to the discharge lines by 6-foot "tee" sections. Because of the 29-foot-diameter and 767-pound-per-square-inch (psi) design pressure, they have been stamped as unfired pressure vessels in accordance with the ASME Code. The shells were fabricated from 1¾-inch-thick plates using ASTM A537, Grade A steel. Special sleeve couplings with 2¼-inch harness bolts are unique features used to tie the sphere to the 6-foot pressure piping. The legs of the sphere are also anchored into the concrete slab and beam foundation, which is supported by 48-foot-deep, reinforced-concrete, bell-bottom, cast-in-place, concrete piles (Figure 653).

Buried Steel Pipes. Beyond the air-chamber connections, two buried steel discharge lines on a 37% slope are used. These have 8-foot - 6-inch diameters, are ring-stiffened and field-jointed by sleeve-type couplings on 80-foot centers. Lining is coal-tar epoxy and external coating is coal-tar enamel. These steel pipes end at the upper bend anchor, located at the top of the pumping plant bowl, where the pipe profile bends down to the gentle slope of the original ground.

Prestressed-Concrete Cylinder Pipes. The main length of the twin discharge lines begins on the downstream side of the upper bend anchor. These are 9-foot-diameter, prestressed-concrete cylinder pipes (Figure 654) and were designed and installed following criteria described in Chapter I of this volume.

Installation of these 9-foot discharge lines involved two phases. In the first phase, the easterly discharge line was installed to serve the initial pumps, Nos. 3, 4, 5, and 6. At the upper bend anchor, a temporary intertie connects the westside manifold and steel pipe to the main east discharge line and transports flow from Pump No. 3. In the second phase, the west discharge line presently is being installed. When this second line is complete, the intertie will be removed and water will then flow through the two separate discharge lines.

Articulation of the concrete pipe is achieved by using an elastic sealant in the joints instead of cement mortar, in conjunction with six small neoprene blocks added to reduce longitudinal impacts.

Siphon Outlet. The siphon outlet is a typical, steel-lined, concrete-encased structure as described in Chapter I of this volume. This structure has two si-

Figure 652. Manifolds

Figure 653. Air Chamber

Figure 654. Prestressed-Concrete Cylinder Pipe

phon barrels and three outlet bays, the easterly bay being for the future third discharge line. The siphon barrels have crests above the canal water level. This system allows a one-way flow from the pumps, and the hydraulics of the structure prevent canal water from flowing back into the discharge lines. A 10-inch, steel, bypass pipe with valves allows filling of either discharge line from the canal.

Mechanical Features

General

The principal mechanical equipment includes six pumps, six pump discharge valves, two equipment-handling cranes, and auxiliary equipment.

Chapter I of this volume contains information on the mechanical equipment which is common to other State Water Project plants. Information and descriptions which are unique to this plant are included in the following:

Equipment Ratings

Pumps

Manufacturer: Units Nos. 1 and 2—Sulzer Bros. Inc.
Units Nos. 3, 4, 5, and 6—Allis-Chalmers Manufacturing Co.

Type: Vertical-shaft, single-stage, centrifugal

Pumps Nos. 1, 2, 5, and 6

Discharge, each:	276 cfs
Total Head:	569 feet
Speed:	514 rpm
Guaranteed Efficiency:	91.0%
Minimum Submergence at Pump Centerline:	27 feet

Pumps Nos. 3 and 4

Discharge, each:	138 cfs
Total Head:	569 feet
Speed:	720 rpm
Guaranteed Efficiency:	90.0%
Minimum Submergence at Pump Centerline:	27 feet

Units Nos. 3, 4, 5, and 6 are presently installed and operating, while Units Nos. 1 and 2 are under construction and scheduled for operation in 1976.

Pump Discharge Valves

Manufacturer: Units Nos. 1 and 2—Goslin-Birmingham Mfg. Co., Inc.
Units Nos. 3, 4, 5, and 6—Yuba Manufacturing Div., Yuba Industries, Inc.

Type and Size: Units Nos. 1, 2, 5, and 6—42-inch, double-seated, spherical
Units Nos. 3 and 4—30-inch, double-seated, spherical

Cranes

65-Ton Bridge Crane

Manufacturer: Crane Hoist Engineering and Manufacturing Co.

Type: Overhead, traveling, bridge

10-Ton Gantry Crane

Manufacturer: Hopper, Inc.

Type: Outdoor, traveling, gantry

Pumps

Pumps are of the vertical-shaft, single-stage, diffuser-casing, centrifugal type, directly connected to synchronous motors. All pumps rotate counterclockwise as viewed from the motor end (Figures 655, 656, and 657).

Pump casings were embedded in the plant concrete substructure. Pump impeller, shaft, guide bearing and housing, and top casing cover are all removable from above when the motor rotor is removed. The hydraulic thrust and the weight of the rotating parts are carried by a thrust bearing in the motor.

Impellers are one-piece, enclosed, centrifugal, single-suction type, fabricated from cast steel, except Units Nos. 1 and 2 which are stainless steel, and are provided with corrosion-resistant steel (400 series) wearing rings.

Removable and renewable wearing rings are located in the suction and casing covers opposite the wearing rings on the impeller crown and band and are made of 400 series stainless steel. The pump guide bearing is a self-lubricating skirt type.

Initially, all pumps were designed to be started with the water depressed below the eye of the impeller. However, excessive upthrust was experienced when starting Units Nos. 3, 4, 5, and 6 in this manner, and the method of starting was modified to allow the pump casing to be fully watered. Floating of the rotating parts off the thrust bearing shoes was also experienced on these units. To prevent damage to the equipment, a thrust collar was installed in the motor and a balance line between the top and bottom pump cover was installed on Units Nos. 3, 4, 5, and 6. Units Nos. 1 and 2 were designed with a thrust collar in the pump bearing and a balance line between the top and bottom pump covers (see Chapter VII of this volume for detailed discussion of the upthrust and floating during starting).

Pump Discharge Valves

A double-seated spherical-type valve was installed on the discharge side of each pump (Figure 658). The valves are used for shutoffs to prevent backflow through the units when they are stopped and to isolate each pump from its discharge line for inspection and maintenance. Each valve and its appurtenances are located in a separate valve vault at the end of the discharge extension of each pump casing.

Units Nos. 1, 2, 5, and 6 have 42-inch-diameter valves, each weighing approximately 27,500 pounds; and Units Nos. 3 and 4 have 30-inch-diameter valves, each weighing approximately 12,500 pounds.

The operating mechanism for each valve is basically composed of an operating cylinder, piston, piston rod, locking device, and operating lever. The cylinder is double-acting, with the control system set up to simultaneously vent one side of the cylinder to the oil sump tank and allow oil to enter the other side under high pressure from the accumulator tank. The rate of valve movement is controlled by a metering valve on the discharge side of the cylinder.

Each valve plug is rotated by its individual hydraulic system, pressurized by an air-over-oil accumulator. Each system, operating at a pressure of 500 psi, is capable of one opening cycle and two closing cycles, after which the system pressure is reduced to 375 psi.

Equipment in each system includes an oil accumulator; oil sump tank and pumps; air compressor; directional and flow control valves; hydraulic control panel; valve control center; and necessary piping, wiring, and instruments.

The air compressor and two hydraulic oil pumps supply air and hydraulic fluid, respectively, to the accumulator. The compressor and pumps normally are operated automatically but can be operated manually from the valve control center.

The valve seats are oil-operated and are located upstream and downstream of the transverse centerline of the valve. The seals are arranged so that either the upstream or downstream ring can be moved independently. The upstream seat is used as an operating seat, and the downstream seat is maintained in the open position and used for shutoff when maintenance is required on the operating seat or on the pumps.

The pump discharge valve is operated only in the fully open or closed position. The opening and closing

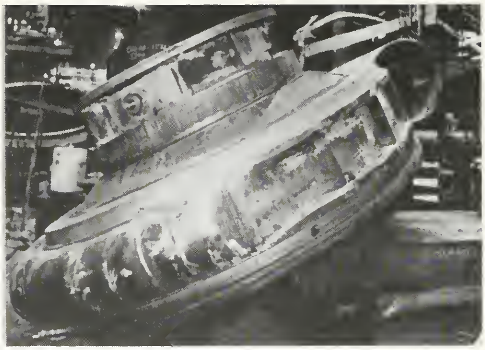

Figure 656. Partial Pump Case Assembly

Figure 657. Pump Casing Assembly

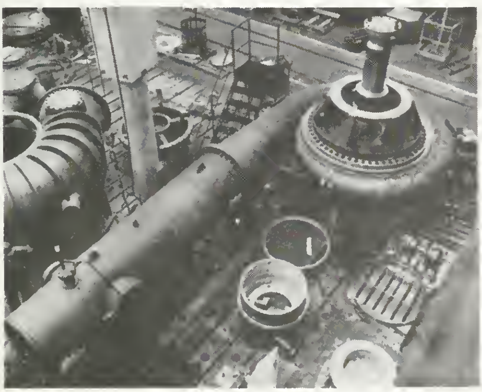

Figure 655. Shop Assembly of Pump

Figure 658. Pump Discharge Valve

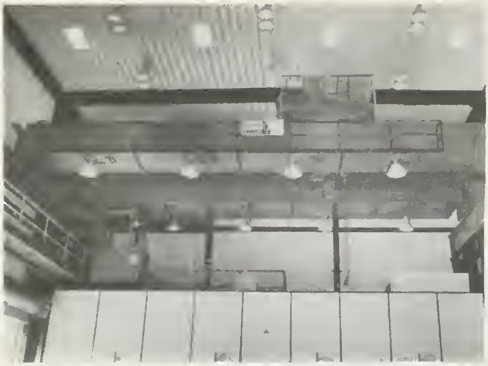

Figure 659. 65-Ton Bridge Crane

Figure 660. 10-Ton Gantry Crane

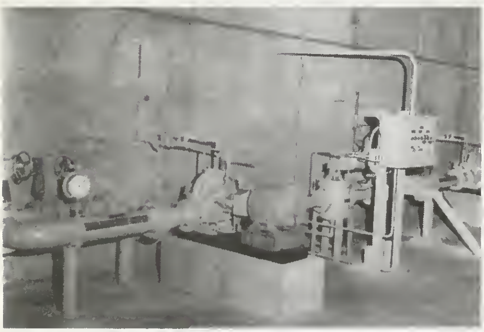

Figure 661. Motor Cooling Water System

of the valve is controlled by a mechanical-electrical sequencer using cam-operated switches and hydraulic valves. The cams are mounted on a shaft which is driven by a 125-volt direct-current motor. The motor is controlled by a reversing starter whose forward and reverse contactors are energized and deenergized by plug and seat-limit switches and the cam-actuated switches previously mentioned.

The valve opens or closes at an approximately uniform rate, but the closing times are different for normal or emergency conditions. In order to minimize the effect of pump operation on the air chamber, the rotary cycle time for emergency (power failure) operation is limited to 4 to 8 seconds (5 seconds was determined by field tests to be the best time). Normal opening or closing was set at 15 seconds.

Equipment Handling—Cranes

The major pumping plant equipment, including pumps, motors, and discharge valves, is serviced by means of a 65-ton, indoor, bridge crane (Figure 659).

The plant also has a 10-ton, outdoor, gantry crane with a trashrack rake. This crane raises, lowers, and transports the intake bulkhead gates and clears the trashracks of debris.

The bridge crane is an electric, cab-operated, overhead, traveling type, with a main 65-ton-capacity hook and an auxiliary 10-ton-capacity hook. A sister-type hook, bored for a lifting pin, is provided on the main hoist. The rated capacities and speeds are as follows:

Rated capacity, tons	65
Number of trolleys	1
Rated capacity of main hoist, tons	65
Rated capacity of auxiliary hoist, tons	10
Maximum lift, main hoist, feet—inches	79′—0″
Maximum lift, auxiliary hoist, feet—inches	81′—6″
Span, feet—inches	49′—7¾″
Hook, Speeds—feet per minute (fpm)	
Main (5 step)	0–3
Aux. (5 step)	0–17
Bridge speed—fpm	95–100
Trolley speed—fpm	40–50

Brakes are provided for hook, trolley, and crane travel. They include both the electric and hydraulic shoe type, with shunt coil and manual release lever.

Access to the crane is provided at two locations from the plant catwalks. One means of access is from the operator's cab to the catwalk on the south wall; the other is by ladder from the operator's cab to the bridge walkway. Access also is provided from the bridge walkway to the catwalk mounted on the east wall of the Pumping Plant.

The 10-ton, outdoor, gantry crane has a trashrack rake and operates on steel rails in the plant gate deck. The lifting mechanism consists of a lifting beam suspended from twin snatch blocks (Figure 660).

The rated capacity and speeds of the gantry crane are:

Rated capacity, tons	10
Number of trolleys	1
Span, feet	14
Hoist speed with maximum working load, fpm (two speeds)	8 to 12 2 to 3
Gantry travel speed with maximum working load, fpm	30 to 40
Trolley travel speed with maximum working load, fpm	3 to 5
Maximum lift, feet	30
Trashrack rake maximum lift, feet	40
Trashrack rake speed, fpm	32
Trashrack rake capacity, pounds	2,000

Hydraulic Transients

An air-over-water surge chamber is used to control the upsurges and downsurges or hydraulic transients caused by emergency power outages at the Pumping Plant. During a downsurge or drop in pressure, water is supplied to the discharge line to prevent its collapse; during a sudden rise in pressure, water is forced into the chamber to control the upsurge or increase in discharge line pressure. Under normal operating conditions, the air chamber is under a constant pressure from the pumping head.

In order for a chamber to be most effective, it is necessary to throttle the reverse flow of water from the discharge line into the chamber, while very little throttling or head loss is required for flow from the chamber. The device used to accomplish this is a differential orifice designed to have approximately 2.2 times as much head loss for return flow into the air chamber as for flow from the chamber. This orifice was installed between flanges located at the base of the chamber and in the riser pipe from the discharge line.

Auxiliary Service Systems

The auxiliary service systems at the plant are described in Chapter I of this volume. Items unique to this plant are discussed below:

Compressed Air System. The compressed air system is different since the pumps were modified to start in the watered condition, and there is no need for an initially installed depressing air system. Just outside the pumping plant building between the two air chambers is a 300-psi air system that provides air for controlling the air-chamber water level. This system consists of one 166-cubic-foot-per-minute (cfm) compressor, one 75-cfm compressor, piping, valves, gauges, float switches, controls, and appurtenances for each air chamber.

Motor Cooling Water System. Water for the cooling water system is supplied by nine pumps (three of which are standby) located in the mechanical gallery. Each pumping unit consists of a split-case, double-suction, single-stage, horizontal, centrifugal pump directly connected to an electric motor, check valve, automatic self-cleaning strainer, and associated valves and piping (Figure 661).

Discharge Line Fill Pumps. The main pumping units must operate with sufficient head against them to ensure safe operation. With the discharge lines empty, two pumps are provided to fill the discharge line to an elevation that is within the pump operating range. The water is drawn from the pump suction inlet or from the pump case extension, strained through a basket strainer, and discharged into the discharge line downstream of the discharge valve.

Due to the limited usage of this system and the limited space to install it, the pumps were connected in series. The first pump will fill approximately one-half of the discharge line while the second pump rotates freely. The second pump is then switched on and, with both pumps operating in series, the remainder of the discharge line is filled.

Electrical Features

General

The electrical installation includes a 230-kV switchyard; power transformers; motors; switchgear; and auxiliary systems for station service, communication, and protection of equipment and personnel. The interconnections are shown on the reference drawings at the end of this chapter.

Chapter I of this volume contains information on the electrical equipment and systems for this plant which are common to other plants in the Project. Information and descriptions which are unique to this plant are included in the following sections.

Description of Equipment and Systems

The six motors are started full-voltage with water in the pump case. They are connected to a 13.8-kV system and operated and protected by metal-clad switchgear (Figure 662). The motor neutrals are grounded through the high-voltage winding of a distribution transformer, and a resistor is connected to the transformer low-voltage winding. This combination limits ground fault currents and is used to detect abnormal ground currents. Lightning arresters and capacitors provide surge protection for each motor.

Two power transformers reduce voltage from 230 kV to 13.8 kV for operation of motors and the station service system. They are connected to the switchyard with overhead conductors and to the switchgear with nonsegregated-phase bus. The 230-kV switchyard includes two breakers, bypass switch, high-voltage revenue metering, and lightning arresters.

The station service system utilizes a double-ended substation containing two transformers and interconnecting main, tie, and distribution breakers (Figure 663). The transformers reduce voltage from 13,200 to 480 volts.

Switchboards at each unit include protective relays,

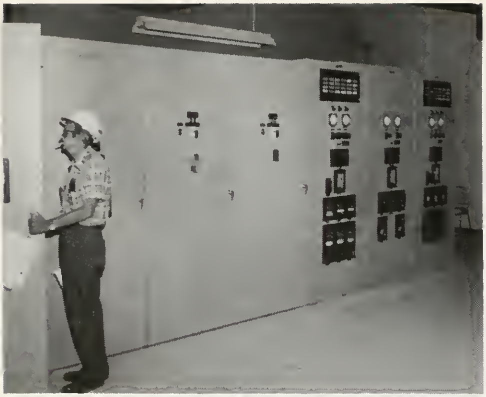

Figure 662. 15-kV Switchgear

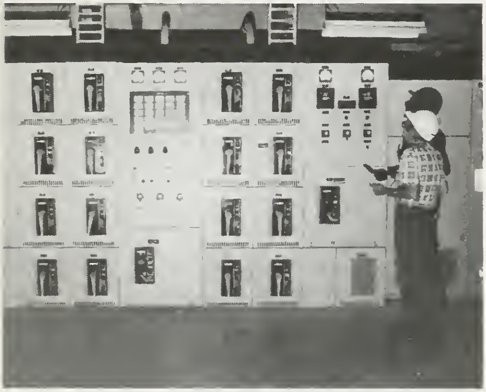

Figure 663. 480-Volt Station Service Substation

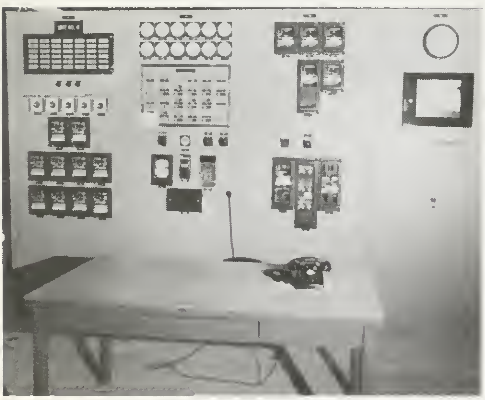

Figure 664. Unit Control Board

instruments, meters, annunciators, and control devices. They are the duplex walk-in type (Figure 664).

A computer control system is installed in the plant control room for normal operation. The plant also may be operated manually from the switchboards or from a remote system. The plant control system will operate, monitor, log data, annunciate, and display all requirements of the plant and switchyard. Volume V of this bulletin describes the plant and remote control systems.

Equipment Ratings

Motors

Manufacturer: Allis-Chalmers Manufacturing Company
Type: Vertical-shaft, synchronous
Volts: 13,200
Power factor: 95%

Motors Nos. 3 and 4

Horsepower: 11,600
Speed: 720 rpm

Motors Nos. 1, 2, 5, and 6

Horsepower: 22,500
Speed: 514 rpm

Power Transformers

Manufacturer: Federal Pacific Electric Company
Volts: 230-13.8/8.72 kV
Taps: In the high-voltage winding, 2½ and 5% above and below rated voltage
kVA: 35,600/47,500
Type: OA/FA
Connection: Wye-Delta

Station Service

Number of transformers: 2
Volts: 13,200—480Y/277
Phase: 3
kVA: 1,000/1,333
Type: AA/FA
Emergency engine-generator: 170 kW, 480Y/277 volts, 3 phase

Motor Starting Method

The motors are started with full voltage and with water in the pump case. Daily starting for off-peak pumping, with the resulting severe duty on the motors, required consideration of alternatives during selection of the starting method.

The first method considered for starting was with water depressed below the impeller on all units. Two smaller motors were to be started full-voltage. The four larger motors were to be started at reduced voltage to meet the inrush requirements of the utility company and to reduce the severe duty on the motors. A three-winding transformer was selected to provide the reduced voltage for starting. This transformer would have a high-voltage winding and two separate low-voltage windings. With a motor started across one of these windings, the transformer has a high value of winding impedance. The result would have been that the motor would be started essentially with a high-impedance transformer, and a reduced voltage on the motor terminal results. As the motor speed increases, the voltage drop of the transformer decreases and reaches normal at synchronous speed, and full voltage is applied to the motor terminals. This starting method was rejected when bids for the three-winding transformers were rejected because they were much higher than estimated.

The second starting method affected only the larger motors, since the larger motors were to be started full-voltage. It consisted of providing reduced voltage by means of an 8.72-kV center tap on the transformer windings (Figure 665). After the motors were sychronized, transformer windings were switched to provide full voltage. The installation was completed and operated satisfactorily electrically.

The third and final starting method was developed after start of operation when the unforeseen upthrust and floating pump characteristics became apparent, as discussed previously. Full-voltage watered starts were then investigated. Tests were conducted and motor designs examined to determine if the motors could be started under those conditions. By changing amortisseur windings and resistance in the field circuit during starting, the motors developed sufficient torque for synchronization. Inrush current and resulting voltage drop were within limits which were modified by the utility company from its original requirements. Costs of the change were relatively low. The new conditions of starting will impose a more severe duty on the motor and possibly a reduction in life. This possibility was accepted to gain the more reliable starting conditions. This starting procedure also allowed the pumps to start satisfactorily and avoided the need to modify their starting configuration.

230-kV Interconnections

The switchyard is supplied by a single transmission line (Figure 666). The two power transformers are supplied from two bays in the switchyard, each with a circuit breaker. To enable removing either breaker from service for maintenance, a bypass switch was installed. Normally, the switch is in the open position; however, during breaker maintenance, the switch is closed and both transformers are supplied through one breaker. Costs were thus kept to a minimum without a sacrifice in protection and flexibility.

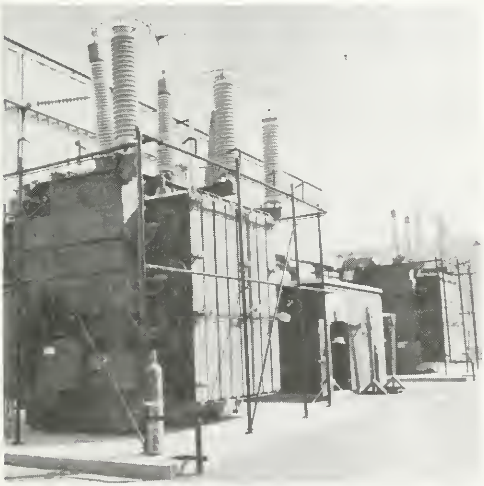

Figure 665. 35.6/47.5-MVA Transformers

Figure 666. 230-kV Switchyard

Construction

Contract Administration

General information about the major construction and supply contracts for the Pearblossom Pumping Plant and discharge lines is shown in Table 13. The principal construction contracts were Pearblossom Pumping Plant Site Development, Specification No. 67-18; Pearblossom Pumping Plant, Specification No. 68-44; Pearblossom Pumping Plant Discharge Line, Specification No. 69-25; and Completion of Pearblossom Pumping Plant, Specification No. 70-17.

Excavation

Major excavation was done under the site development contract, Specification No. 67-18, and included excavation of the intake canal, spill basin, and foundation for Pearblossom Pumping Plant (Figures 667, 668, and 669). A total of 99 days was required.

No unusual problems were encountered during the excavation. Ripping was not required, and scrapers were easily loaded when pushed by a large dozer. The excavation was hauled to spoil areas adjacent to the project or stockpiled for later use in embankments.

Ground Water. Ground water was first encountered on the west side of the plant bowl about 51 feet above subgrade. On the east side of the bowl, the water table was 30 feet lower. Differential levels resulted from an impervious low-angle fault crossing the plant site from north to south. Ground water encountered at the higher elevations was mixed with excavated material and removed. Most of the ground water encountered was at the lower elevations and was removed by pumping. Drains to extract ground water were used only in the service bay area. When the excavation reached subgrade elevation in the service bay, permanent trench drains were installed to convey

TABLE 13. **Major Contracts—Pearblossom Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Site development	67-18	$1,179,597	$1,103,945	--	5/12/67	1/22/68	Altfillisch-Fulton Co.
Power circuit breakers	68-13	61,140	63,731	$ -1,571	3/ 7/68	5/14/71	General Electric Co.
Pumps	68-24	824,850	941,000 (Est.)	6,226*	9/27/68	12/74 (Est.)	Allis-Chalmers Mfg. Co.
Bridge cranes (including A. D. Edmonston Pumping Plant)	68-32	829,400	882,679	14,774	2/20/69	8/27/70	Crane Hoist Engineering & Mfg. Co.
Pearblossom Pumping Plant	68-44	4,769,985	5,570,178	416,010	11/ 8/68	11/26/70	Peter Kiewit Sons' Co.
Power transformers	68-47	327,645	346,592	778	8/19/69	3/12/71	Federal Pacific Electric Co.
Pump discharge valves	69-03	477,538	556,062	13,727	5/13/69	7/25/72	Yuba Industries, Inc.
Motors	69-14	1,247,500	1,535,000 (Est.)	--*	8/26/69	12/74 (Est.)	Allis-Chalmers Mfg. Co.
13.8-kV switchgear	69-23	210,828	239,720	4,813	2/24/70	8/25/71	Westinghouse Electric Corp.
Discharge line	69-25	1,905,000	2,016,868	70,746	1/23/70	4/ 5/71	Stolte, Inc. & Santa Fe Engineers, Inc.
Station service substation and distribution centers	70-01	111,474	124,224	9,603	3/10/70	11/15/71	Federal Pacific Electric Co.
Switchboards	70-11	164,769	169,066	—77	4/16/70	8/10/71	General Electric Co.
Completion contract	70-17	3,074,815	3,700,082	259,906	8/ 3/70	2/ 7/73	Gunther & Shirley Co.
Strong-motion acceleration monitoring system (including Devil Canyon Powerplant and Perris Dam)	71-13	86,028	94,219	--	6/ 9/71	12/4/72	Electra-Physics
Pumps—Phase II	72-10	798,978	807,000 (Est.)	--*	11/ 3/72	4/76 (Est.)	Sulzer Bros., Inc.
Valves—Phase II	73-07	619,320	650,000 (Est.)	--*	5/15/73	1/76 (Est.)	Wismer & Becker Contracting Engineers
Motors—Phase II	73-09	1,116,400	1,205,000 (Est.)	*	8/10/73	5/76 (Est.)	Allis-Chalmers Mfg. Co.
Switchboards—Phase II	73-12	84,703	93,500 (Est.)	--*	7/24/73	3/75 (Est.)	Hatch, Inc.
15-kV switchgear—Phase II	73-25	85,990	98,000 (Est.)	--*	8/29/73	3/75 (Est.)	Delta Switchboard Co.
2nd discharge line	73-35	2,410,946	2,652,000 (Est.)	11,276*	11/29/73	9/75 (Est.)	Sully-Miller Contracting Co.
Completion contract—Phase II	73-41	793,333	873,000 (Est.)	20,828*	1/30/74	1/76 (Est.)	The Shirley Co.

* As of November 1974

the water to the southwest corner of the deep sump where it was removed from the excavation by pumping. Ground water seepage was encountered only on the faces of the excavation for the walls of the service bay deep sump.

Structural Excavation

Excavation of the pumping plant foundation, discharge lines, and manifolds commenced in October 1968. By February 1969, 95% of the excavation was completed, and the remainder was performed as construction progressed. The structural excavation for the Pumping Plant extended 82 feet below the general level of the bowl invert.

The granitic rock foundation was ripped with large tractors equipped with single-shank rippers. The rock broke down further into coarse sand sizes during handling.

The foundation for the discharge lines was excavated primarily in alluvial material. A tractor with a dozer blade and slope bar made the excavation without ripping. Temporary cut slopes of ¾:1 were quite stable.

Stockpiled material from the plant and discharge line foundation excavations was loaded into 16-cubic-yard trucks by rubber-tired front-end loaders. Most of the excavated material was hauled to the north spoil area where suitable backfill material was stockpiled and unsuitable material was wasted. Some excavated material from the top of the two discharge line cuts was stockpiled on the south rim of the bowl for structural and common backfill.

Backfill Placement

Consolidated Bedding. Consolidated bedding was placed around the discharge lines from subgrade to about 2 feet above springline. All the bedding material was imported, because material from the plant excavation and the north and east spoil areas was not of specified gradation or strength.

Initially, a blanket of bedding material was placed on the subgrade of the discharge line excavations to provide an even foundation for the steel pipe. After the pipe sections were positioned, saturated bedding material was placed around them. The required consolidation (70% relative density) was easily achieved with 6-inch pneumatic vibrators.

Structural Backfill. Structural backfill material was placed around all concrete structures, corrugated-metal pipes, and in other areas that did not specifically require consolidated bedding or common backfill. Where overexcavation was authorized because of earth slides, cracks, and unstable material, it was backfilled with concrete or structural backfill material.

Concrete sand rejected for use in concrete but meeting the gradation required for consolidated bedding was used as structural backfill. Most of the 1,100 cubic yards of sand used was placed at the east end of the Pumping Plant with the remainder placed on the

Figure 667. Pumping Plant Site Development

Figure 668. Excavation in the Bowl Area

Figure 669. Pumping Plant Excavation

north side. Sand was run through the concrete batch plant to a conveyor system that carried it to the placement location. This operation was so successful that the contractor bought additional sand for use as structural backfill rather than using plant-excavated material.

Approximately 50,000 cubic yards of material from the pumping plant and discharge line excavations was utilized for the remainder of the structural backfilling. Dump trucks, loaded by front-end loaders, were used to transport backfill from the north spoil area. Backfill material on the south rim was handled with the front-end loader and a small dozer. Compaction was performed with regular and vibratory sheepsfoot rollers and hand-operated compactors. With some reworking after testing, all areas met the required 95% relative compaction.

Common Backfill. Common backfill material, obtained from the discharge line and south-slope excavations, was transported from the stockpile to the discharge lines by front-end loaders. Approximately 1,650 cubic yards were used for the final 3½ feet of backfill around and over the discharge lines. It was moisture-conditioned at the stockpile with supplemental conditioning as needed during placement. The compactive effort applied yielded compaction greater than the minimum required (85% for the first 3 feet; 90% for the top 6 inches).

Pneumatically Applied Mortar

A 2-inch layer of wet mix shotcrete was pneumatically applied on the pumping plant load bearing surfaces to prevent air slaking and decomposition of the foundation rock and to provide an easily cleaned surface upon which to place structural concrete. Shotcrete was applied on the load bearing surfaces within 48 hours after reaching final grade. Only 6 to 10 feet of the sloping foundation could be shotcreted within the 48-hour limit, so 1 foot of undisturbed material was left above final grade until shotcreting could be performed.

A 4-inch lining of shotcrete was applied in two cross-berm drainage ditches on the south slope of the pumping plant bowl. The total area of shotcrete applied for both purposes was approximately 6,100 square yards.

Concrete Placement

A total of 440 cubic yards of backfill concrete was placed on load bearing surfaces where overexcavation was required to remove unstable or otherwise unsuitable foundation material. Approximately 36,700 cubic yards of structural concrete was used for the pumping plant structure and appurtenances.

The concrete batch plant, located on the northwest side of the pumping plant bowl, was an automatic plant with one 4-cubic-yard tilting-drum mixer having a rated output of 80 cubic yards per hour (Figure 670).

Figure 670. Contractor's Concrete Batch Plant

An ice house was constructed adjacent to the batch plant. Up to 100% ice was used for mixing water during the summer. The contractor was able to maintain the temperature near the specified 50 degree Fahrenheit level. Adjacent to the batch plant and ice house, a material control building was constructed by the contractor for the Department of Water Resources.

Concrete with 3-inch maximum size aggregate was used for floor slabs at least 15 inches thick and for other sections of the pumping plant structure and appurtenances at least 18 inches thick. A starter mix with ¾-inch maximum size aggregate was used occasionally to prime construction joints in formed areas congested with reinforcing steel. For all other concrete, 1½-inch maximum size aggregate was used, including the top 6 inches of the floor slabs.

Two methods of placing concrete were used. The primary method utilized a series of belt conveyors exclusively. Alternately, a crane with 2-cubic-yard buckets was used in conjunction with the belt conveyors.

Consolidation of the concrete was achieved by using immersion-type, 6-inch, 3-inch, and 2-inch vibrators.

Discharge Lines

Installation of the discharge manifolds, lines, and appurtenances included installation of 46-inch- and 65-inch-outside-diameter, special, sleeve-type couplings; 103-inch-outside-diameter, standard, sleeve-type couplings; valve tapers; and various appurtenances. Field tests included radiographing all butt welds; hydrostatically testing the valve tapers, discharge manifolds, and lines; and testing the coating on interior surfaces for discontinuities, voids, and adequacy of thickness (Figures 671 and 672).

During testing of the discharge manifolds, a pressure of 395 psi was maintained for one hour without a drop in pressure or any visible sign of leakage. An internal pressure of 234 psi was maintained during concrete placement and held until the concrete had attained a compressive strength of 2,500 psi.

The discharge line pipe sections were slipped down the trenches from the top of the plant bowl using a sled mounted on well-greased timber skids. Repairs to the pipe and couplings adjacent to the anchor block were necessitated by misalignment resulting from movement of the anchor block during hydrostatic testing.

Plant Superstructure

The structural steel for the pumping plant superstructure arrived at the job site in late May 1970. The fabricated steel was sandblasted and primed in the field. The column base plates were set in early June 1970 by the use of a 50-ton truck-mounted crane. This same crane was used to erect the structural members. Erection of the superstructure steel started June 22, 1970. The erection of the structural steel was completed November 5, 1970. An excellent job was done.

The insulated metal siding for the superstructure was installed between July 29, 1970 and October 9, 1970. No problems of consequence occurred.

Other Construction

Construction was routine for the switchyard and installation of mechanical and electrical equipment.

Figure 671. Discharge Line No. 2

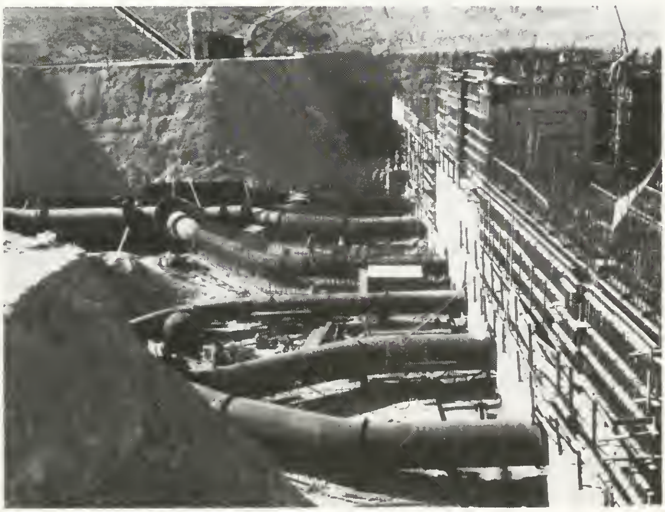

Figure 672. Discharge Manifolds Under Construction

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 673 through 706).

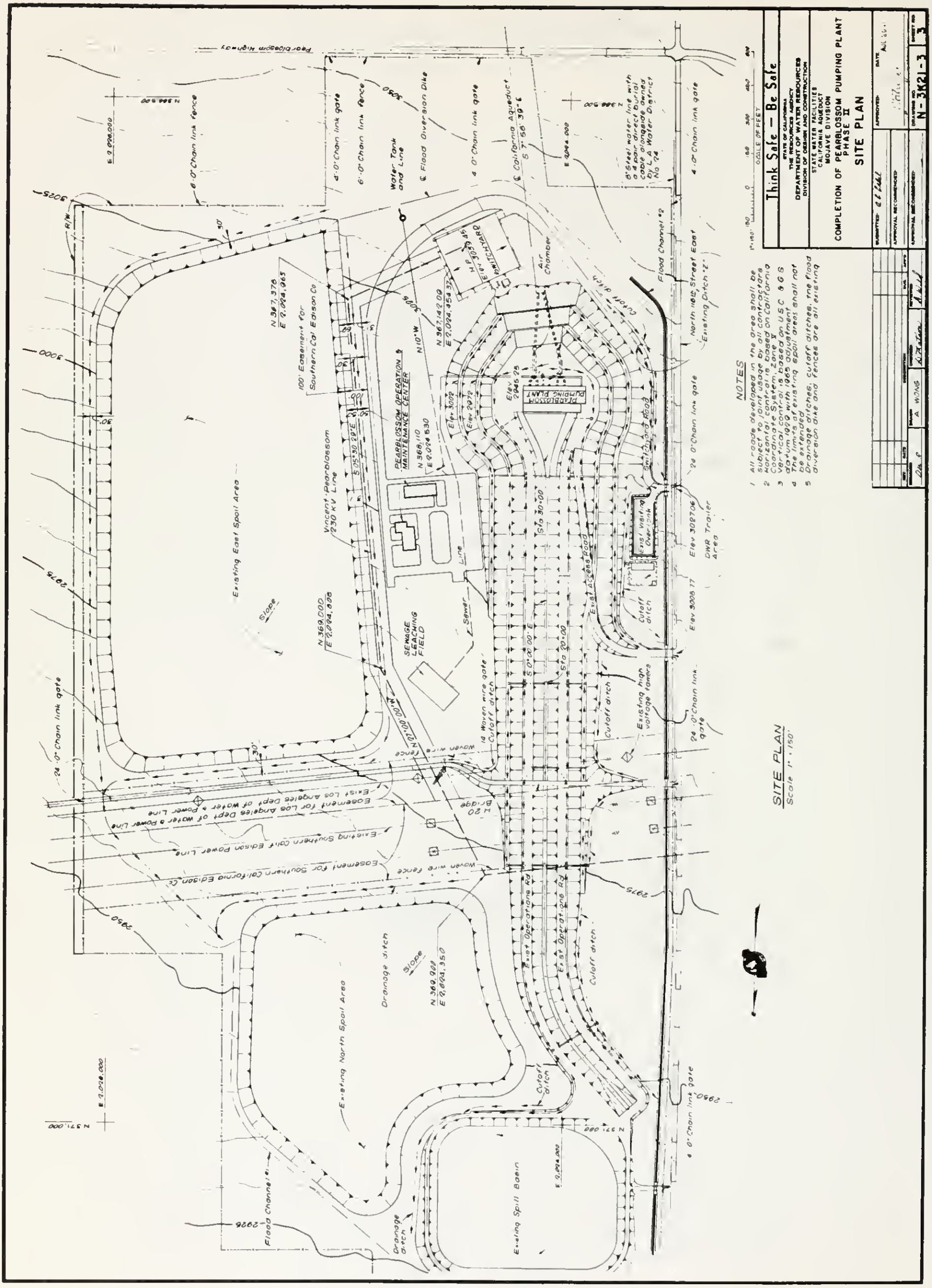

Figure 673. Site Plan

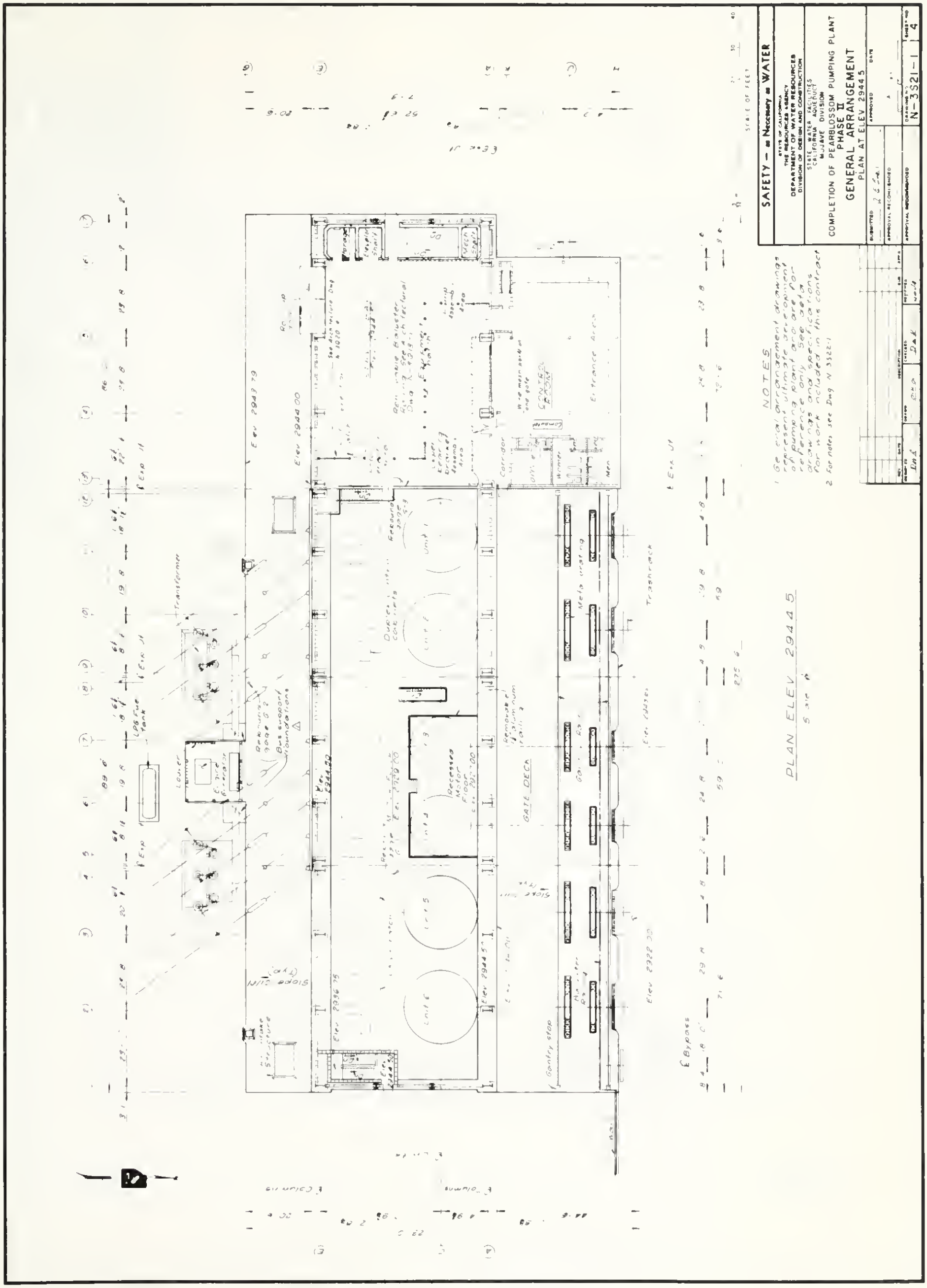

Figure 674. Plan—Elevation 2,944.5

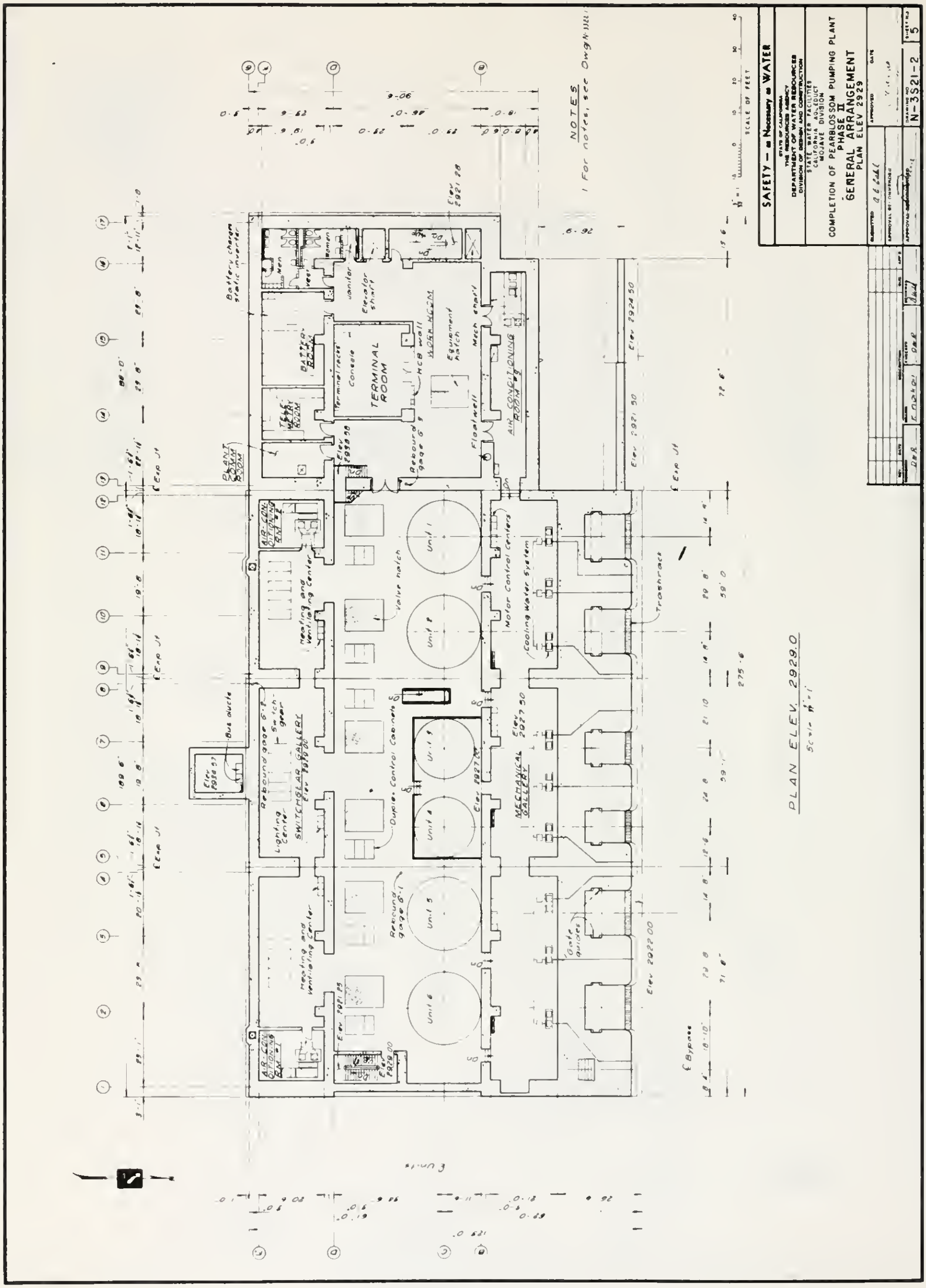

Figure 675. Plan—Elevation 2,929.0

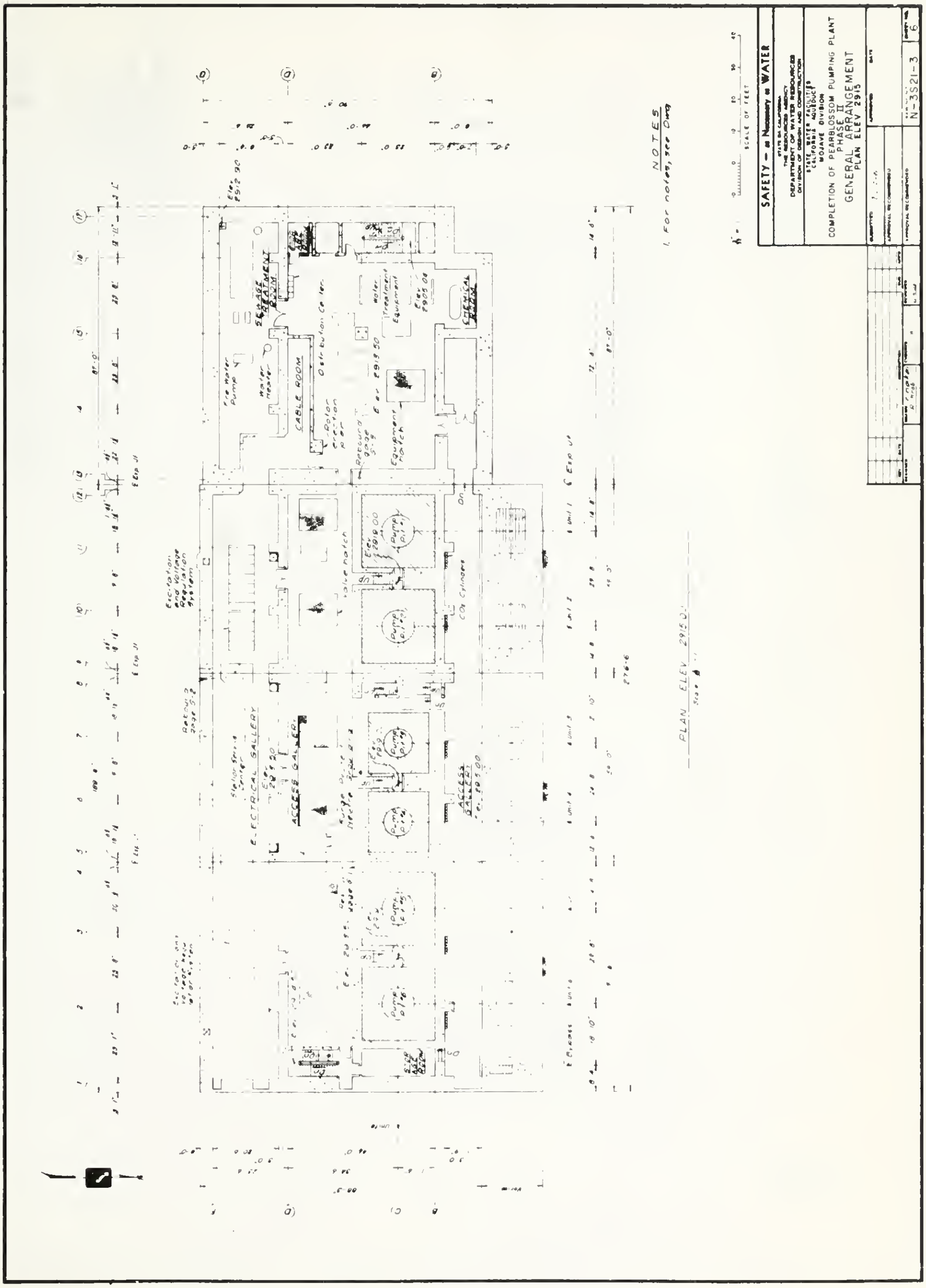

Figure 676. Plan—Elevation 2,915.0

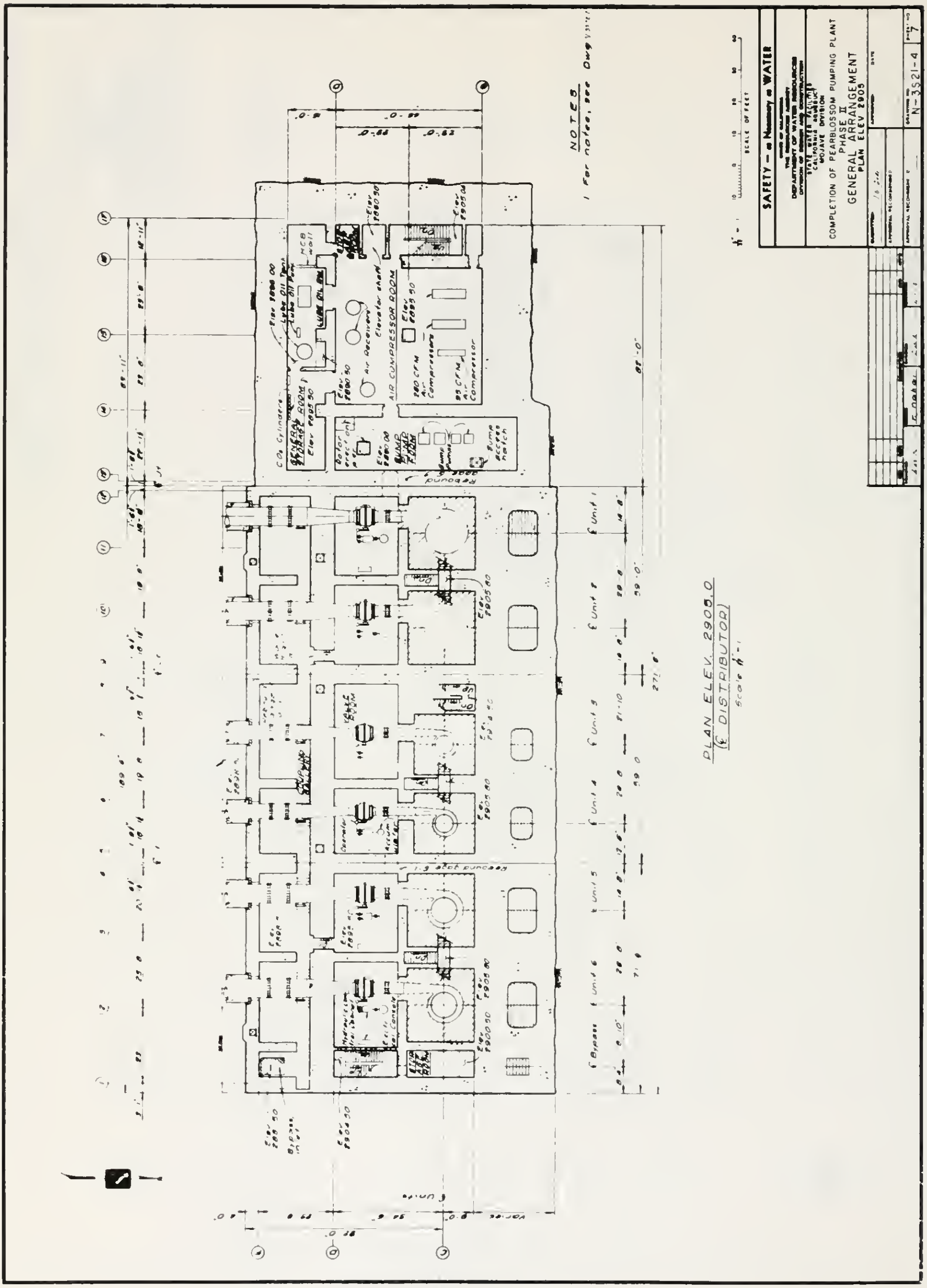

Figure 677. Plan—Elevation 2,905.0

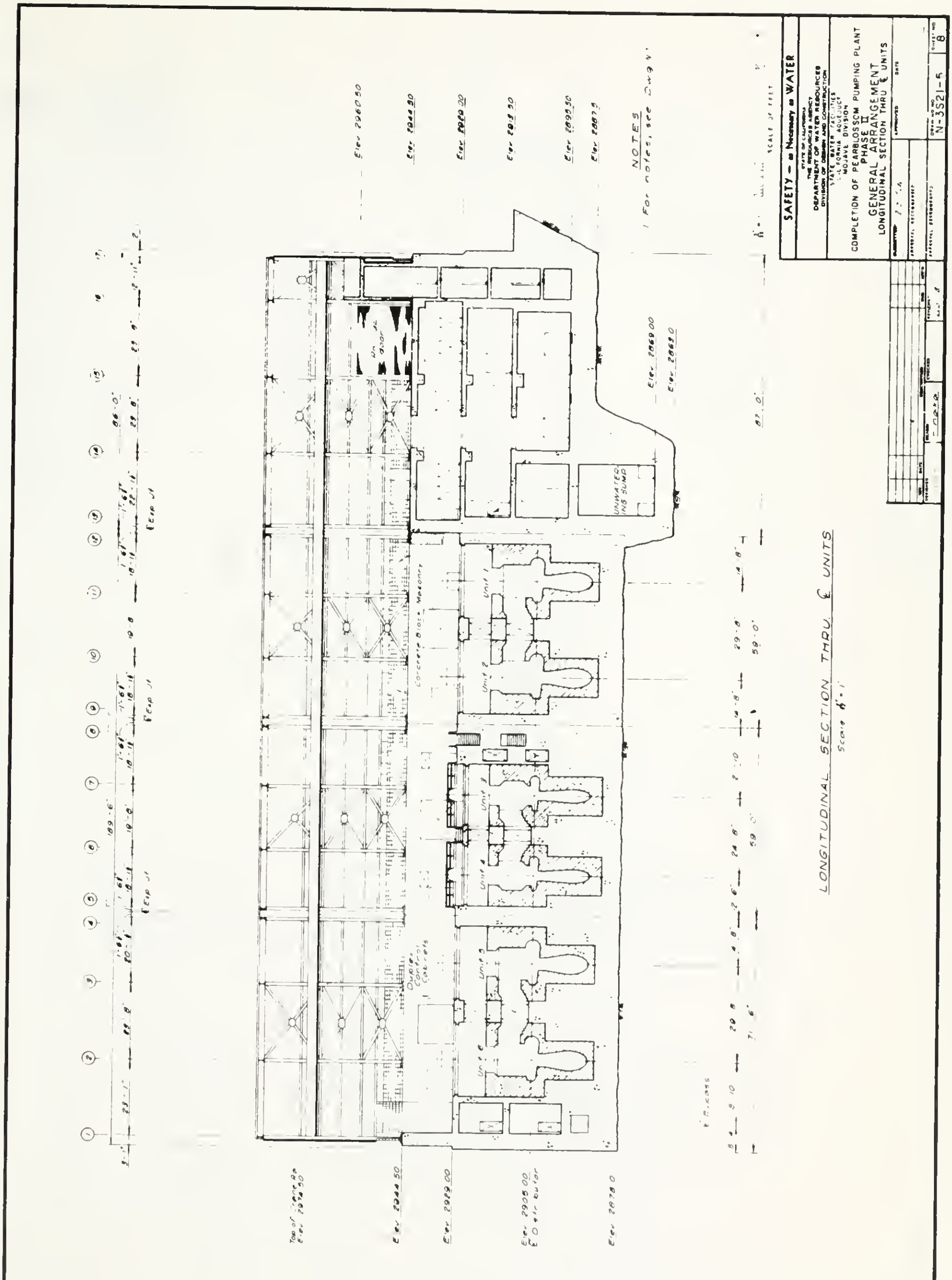

Figure 678. Longitudinal Section

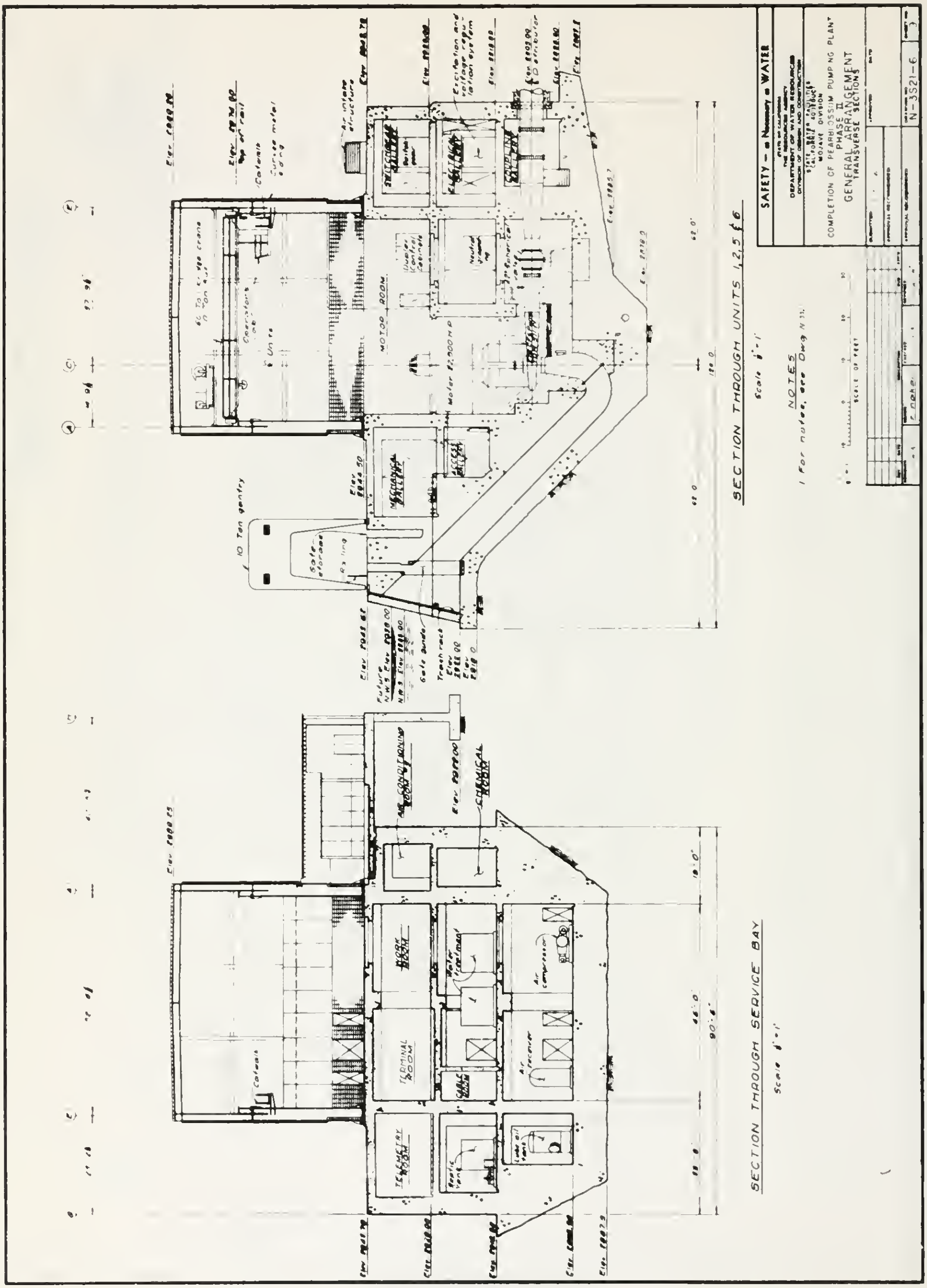

Figure 679. Transverse Section

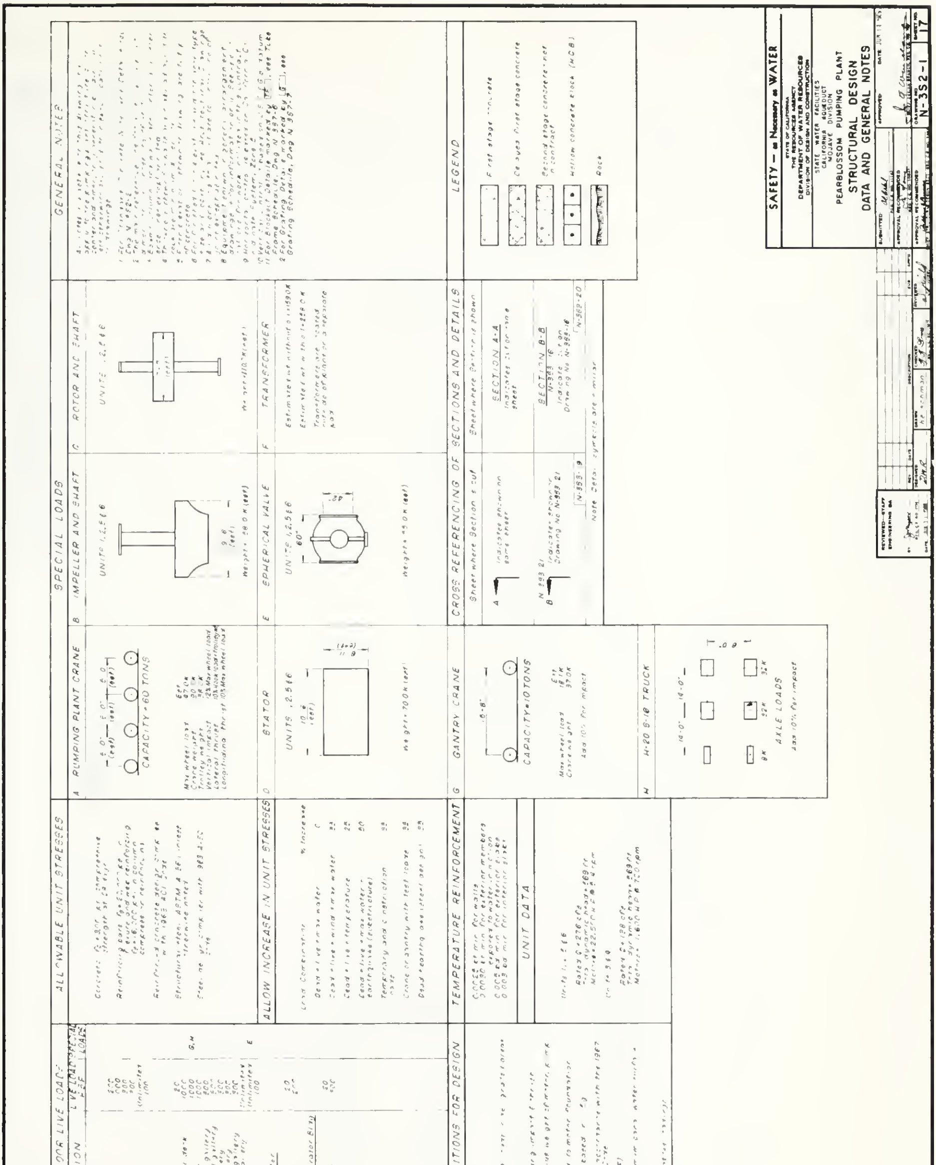

Figure 680. Structural Design Data

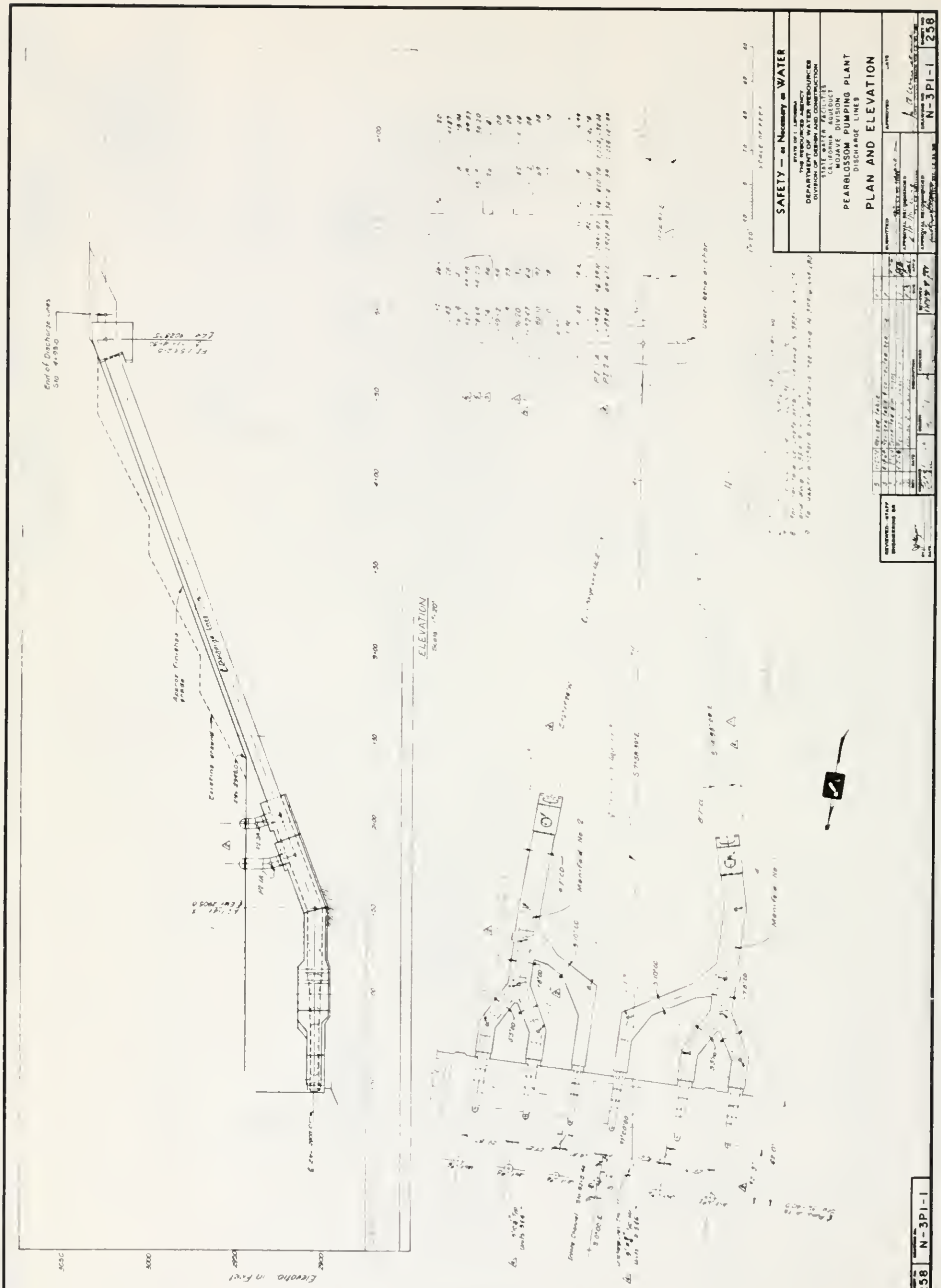

Figure 681. Discharge Line—Plan and Elevation

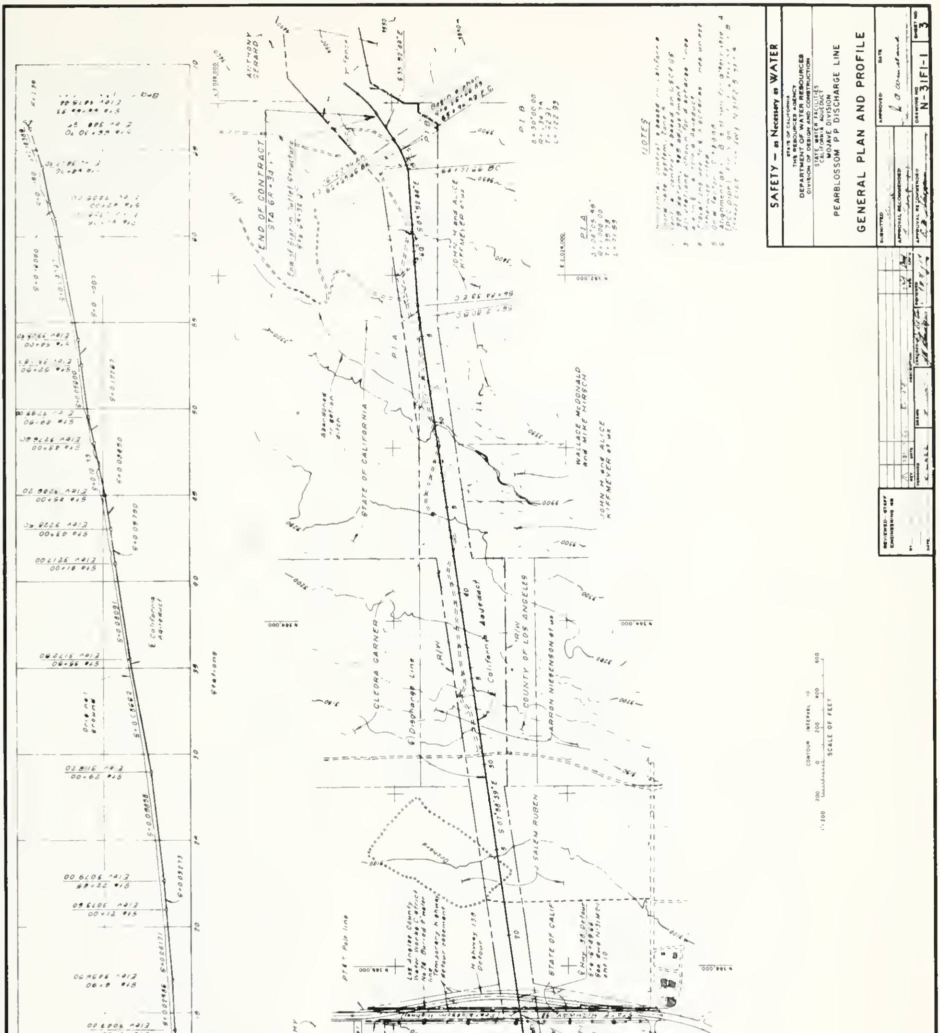

Figure 682. Discharge Line—Plan and Profile

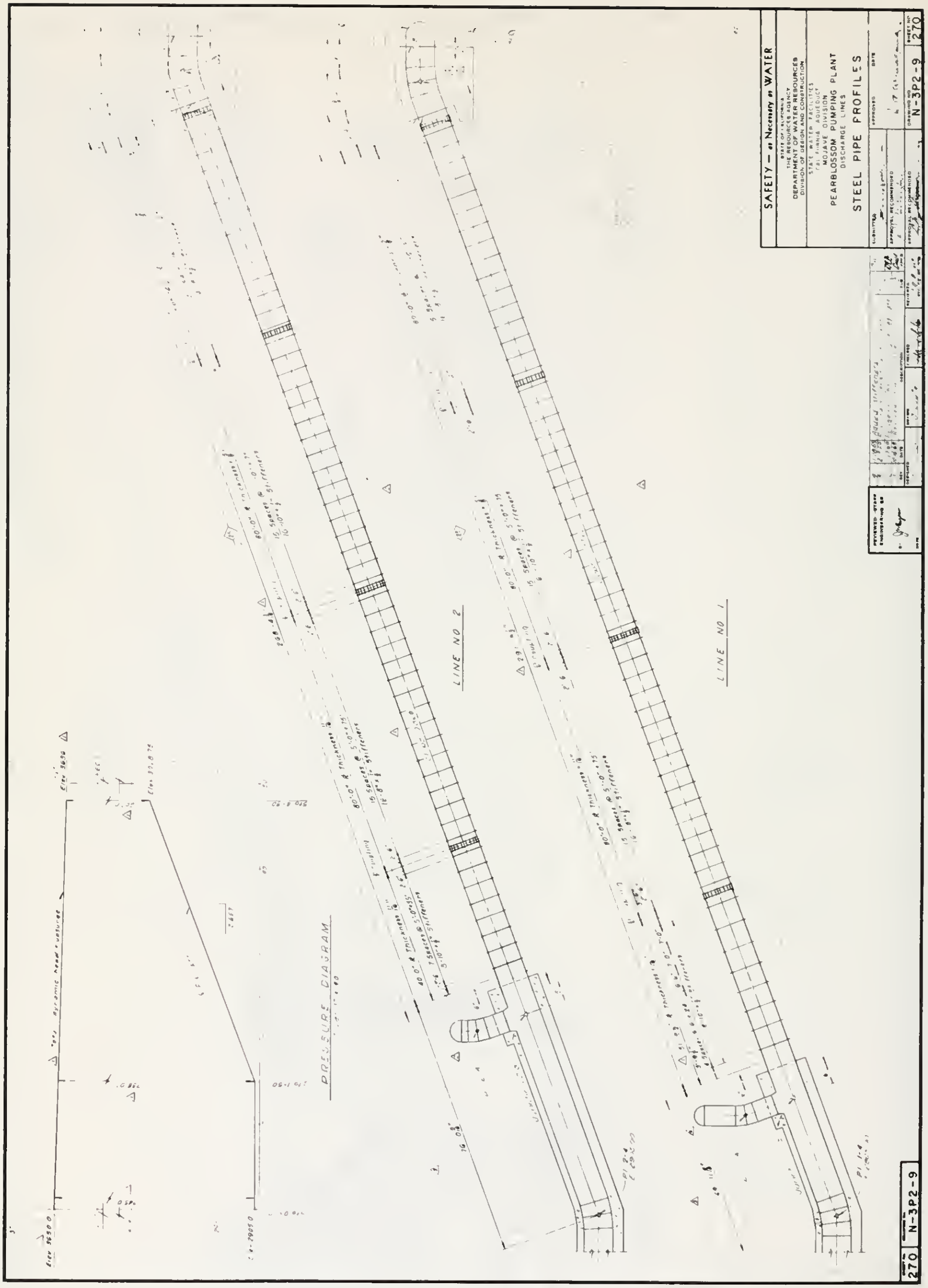

Figure 683. Steel Pipe Profiles

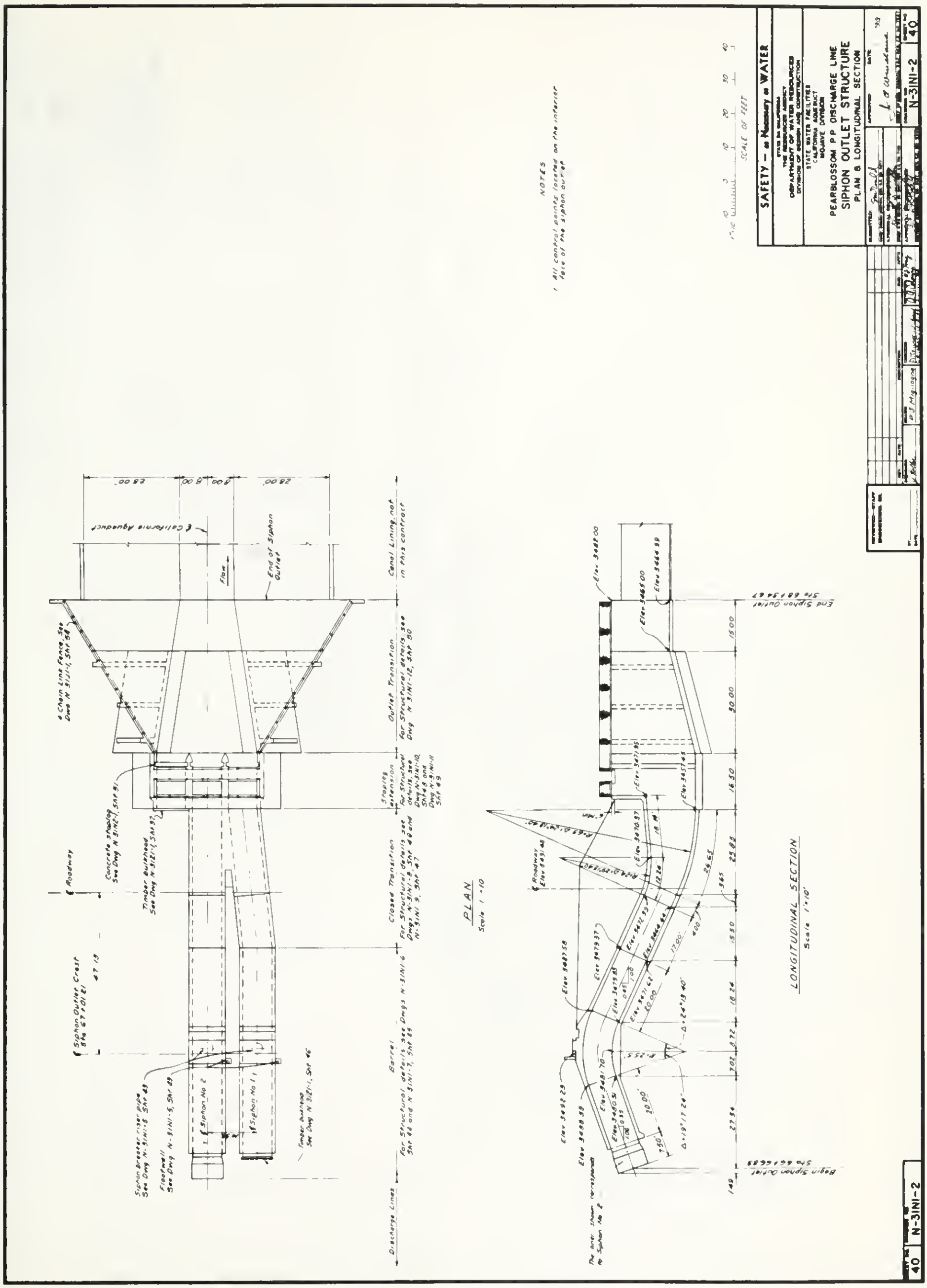

Figure 684. Siphon Outlet

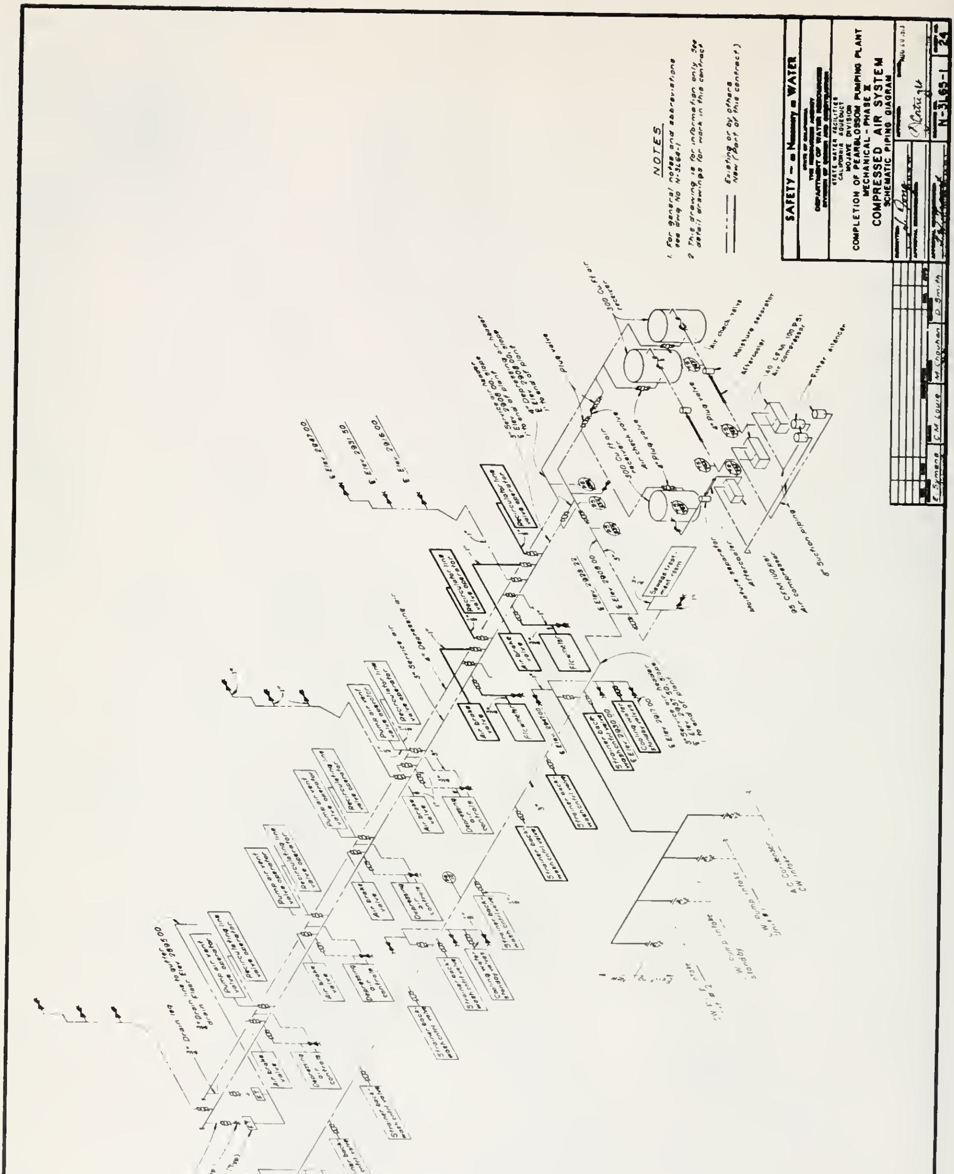

Figure 685. Compressed Air System

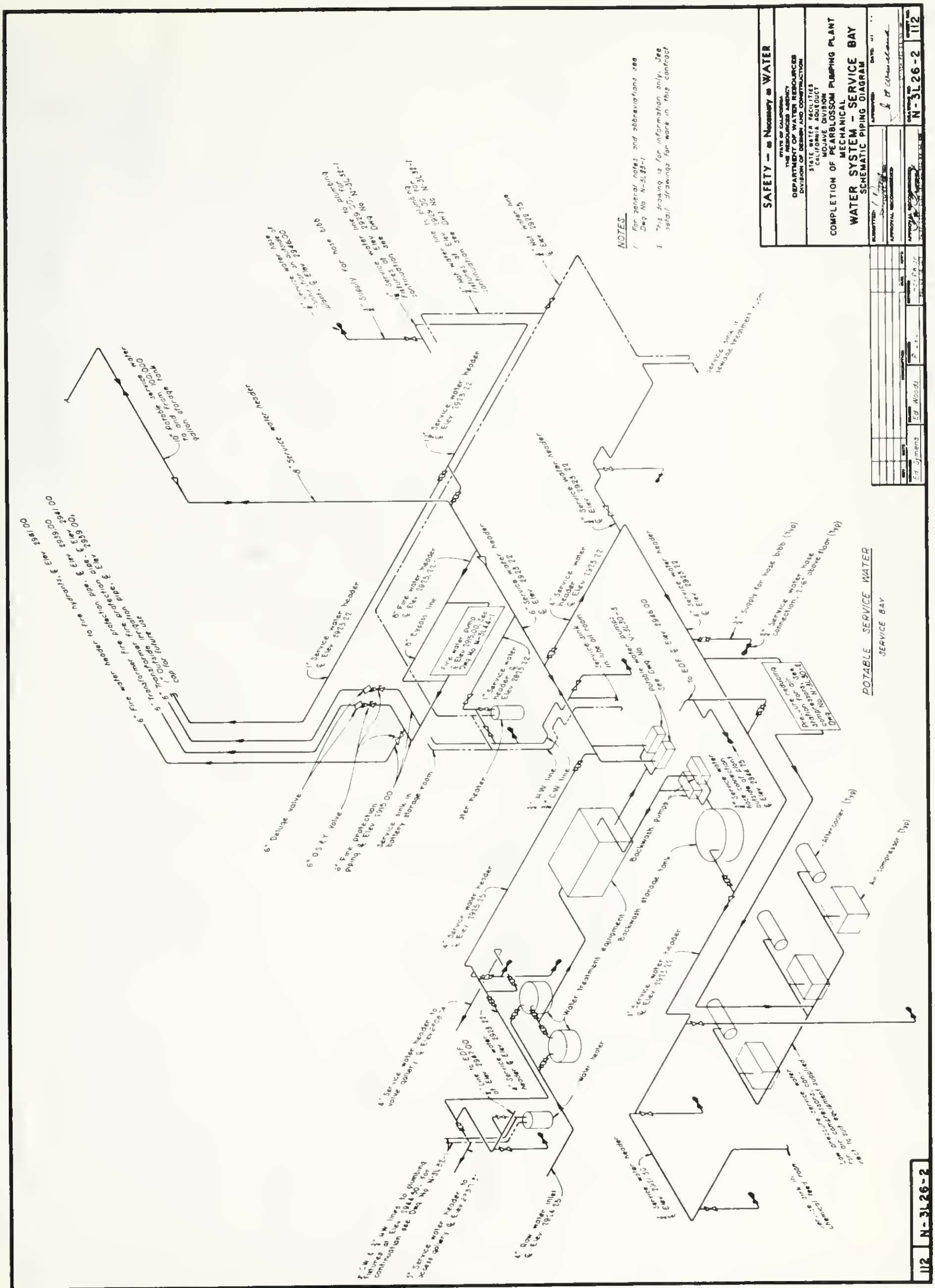

Figure 686. Water System—Service Bay

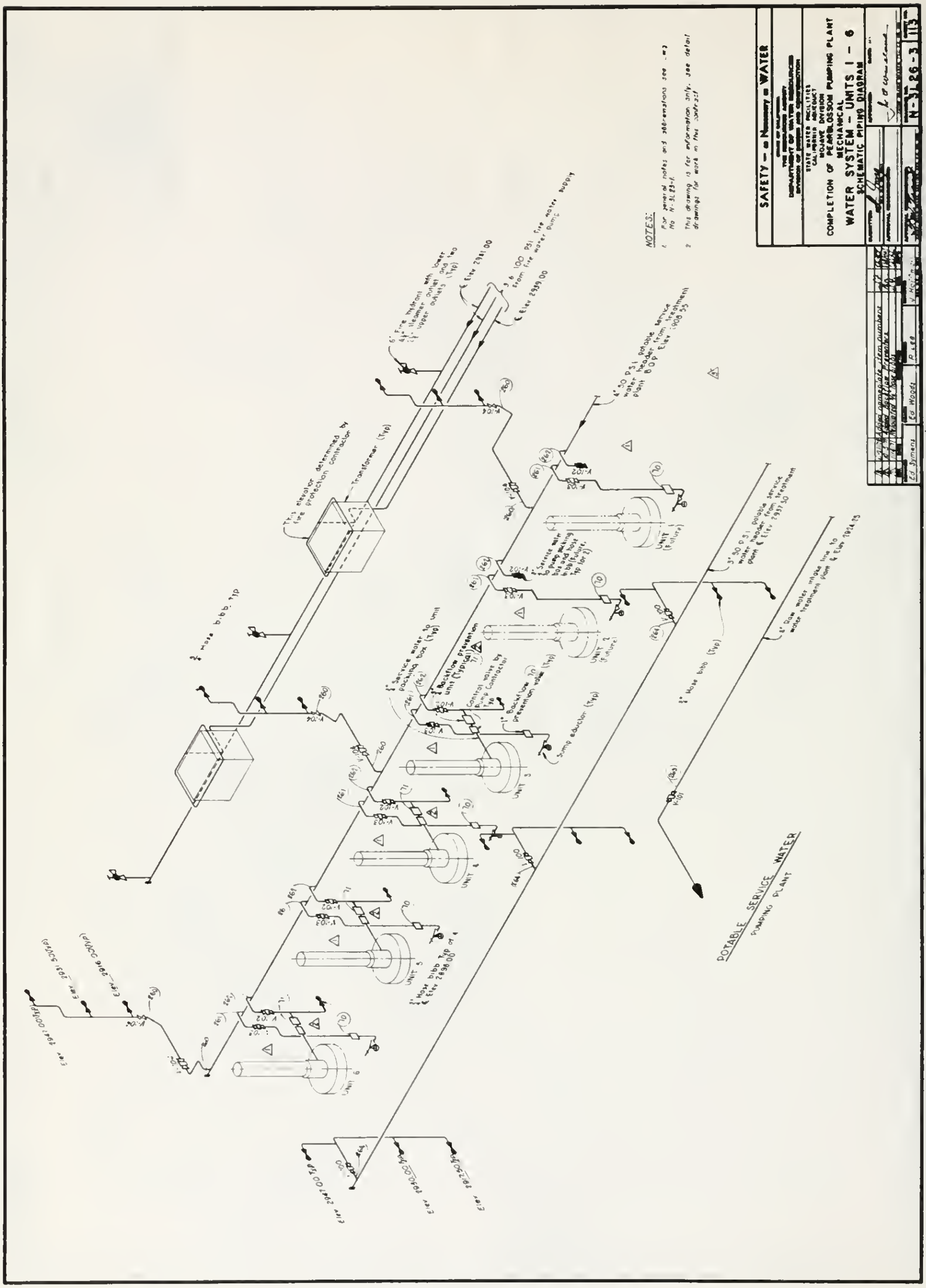

Figure 687. Water System—Units Nos. 1 Through 6

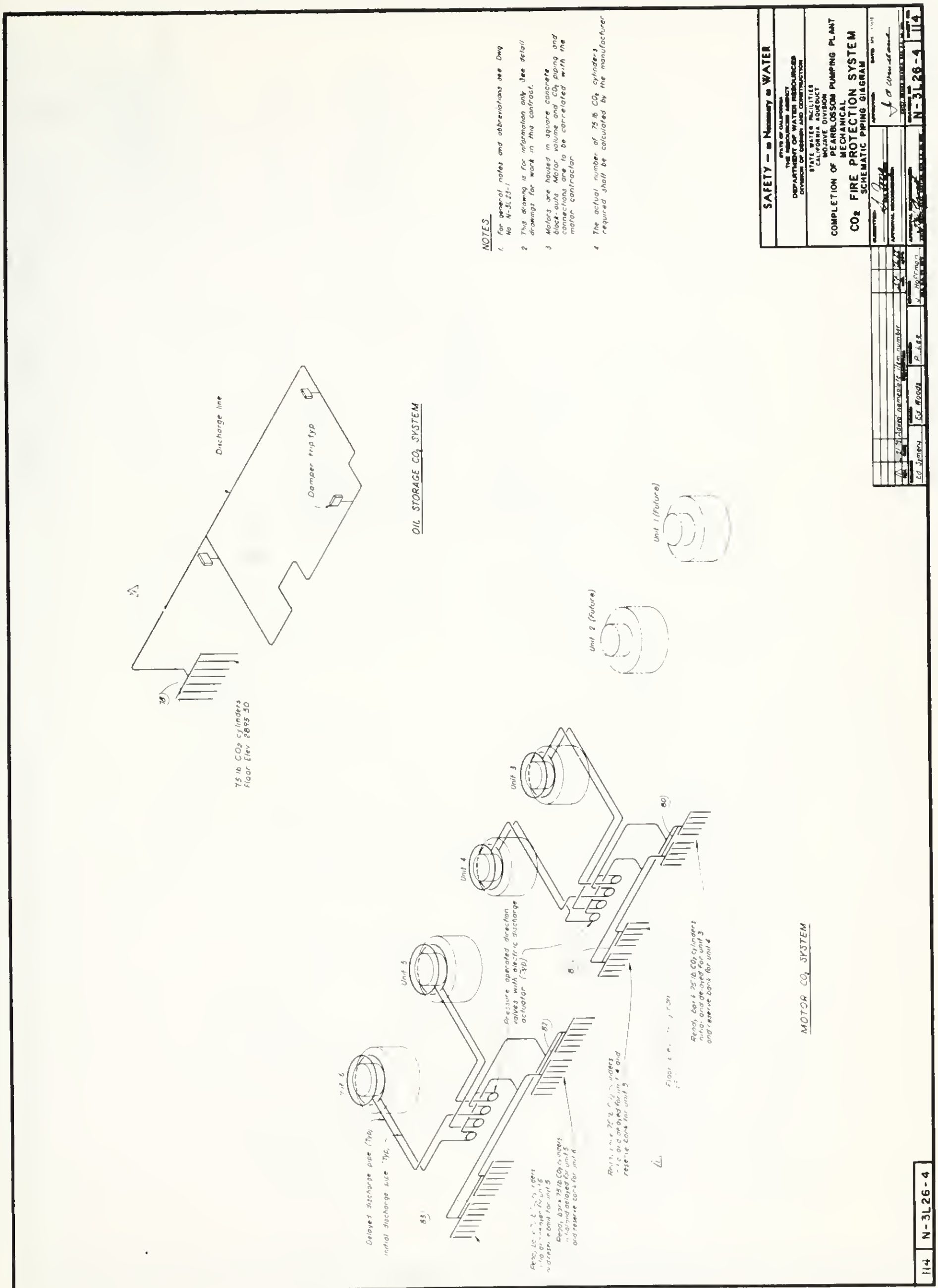

Figure 688. Carbon Dioxide Fire-Protection System

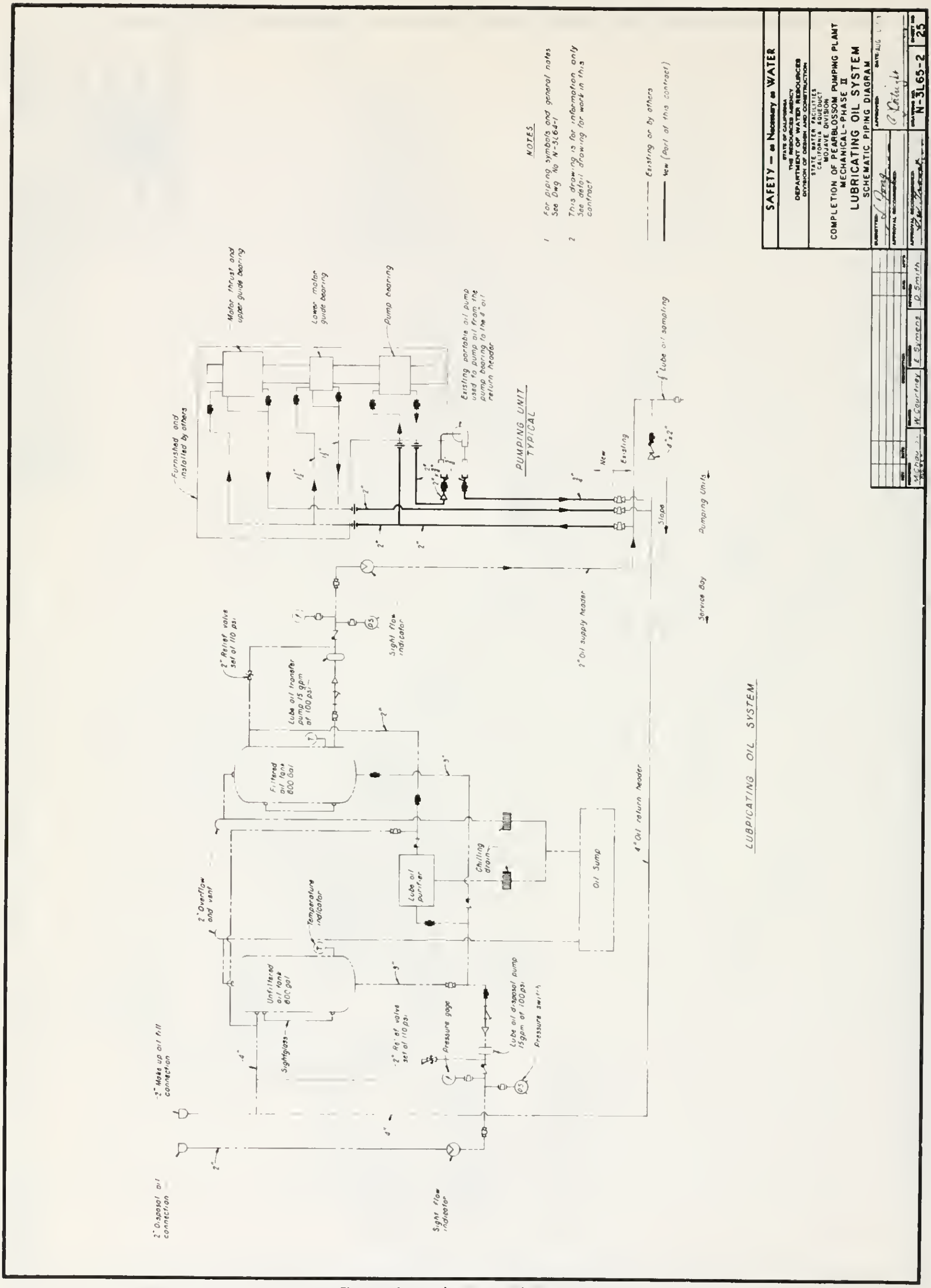

Figure 689. Lubricating Oil System

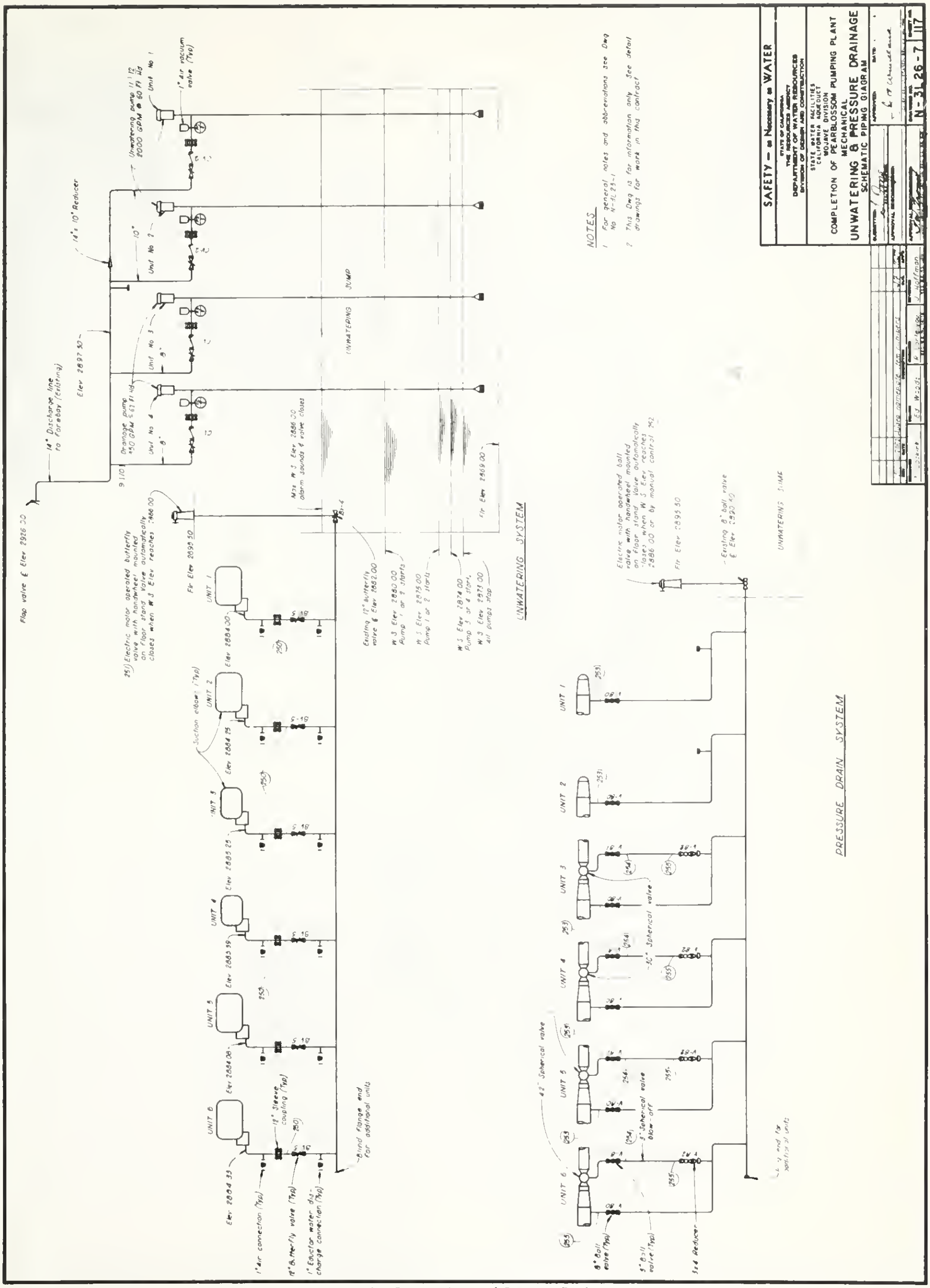

Figure 690. Dewatering and Pressure Drainage

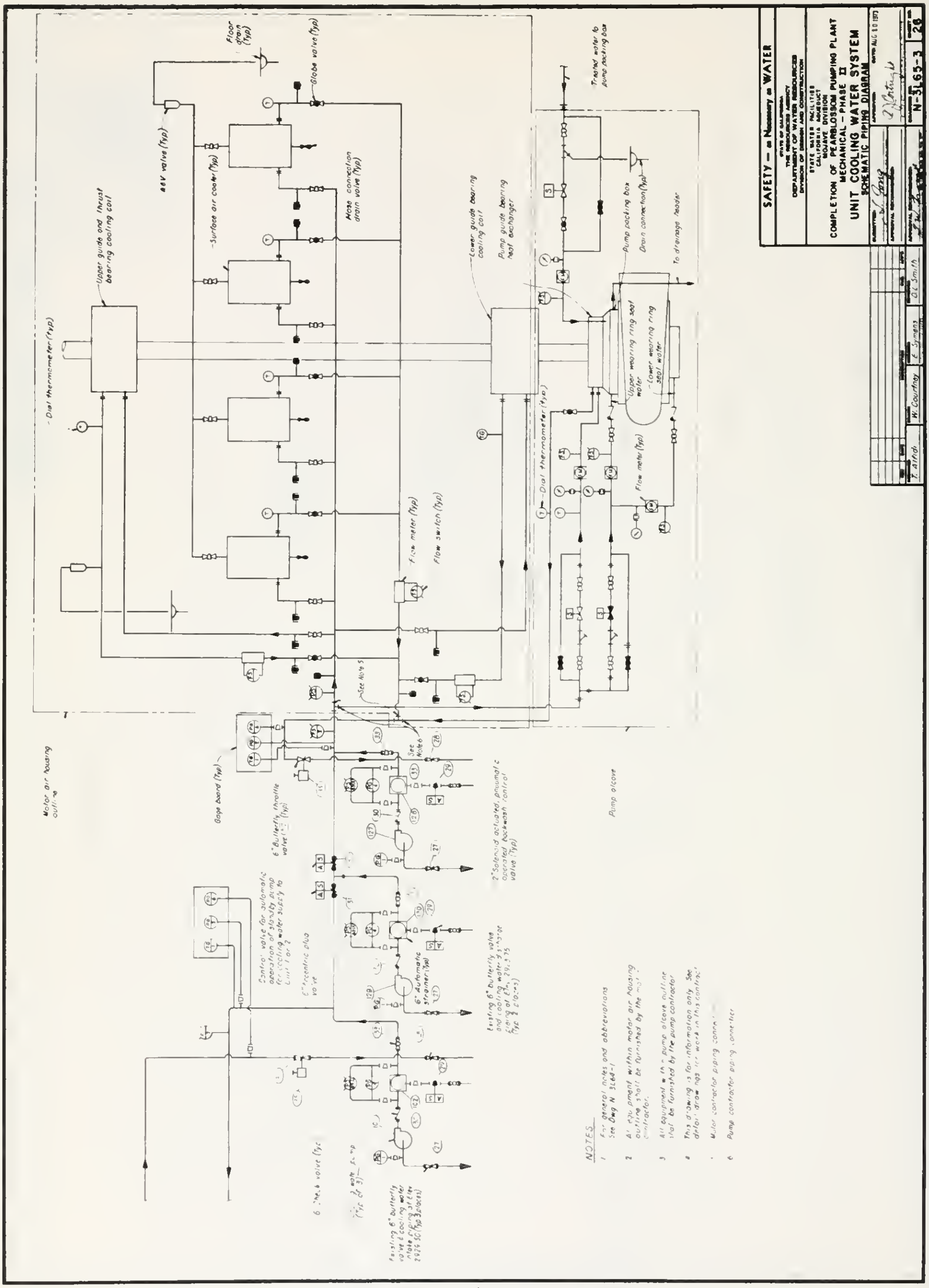

Figure 691. Unit Cooling Water System

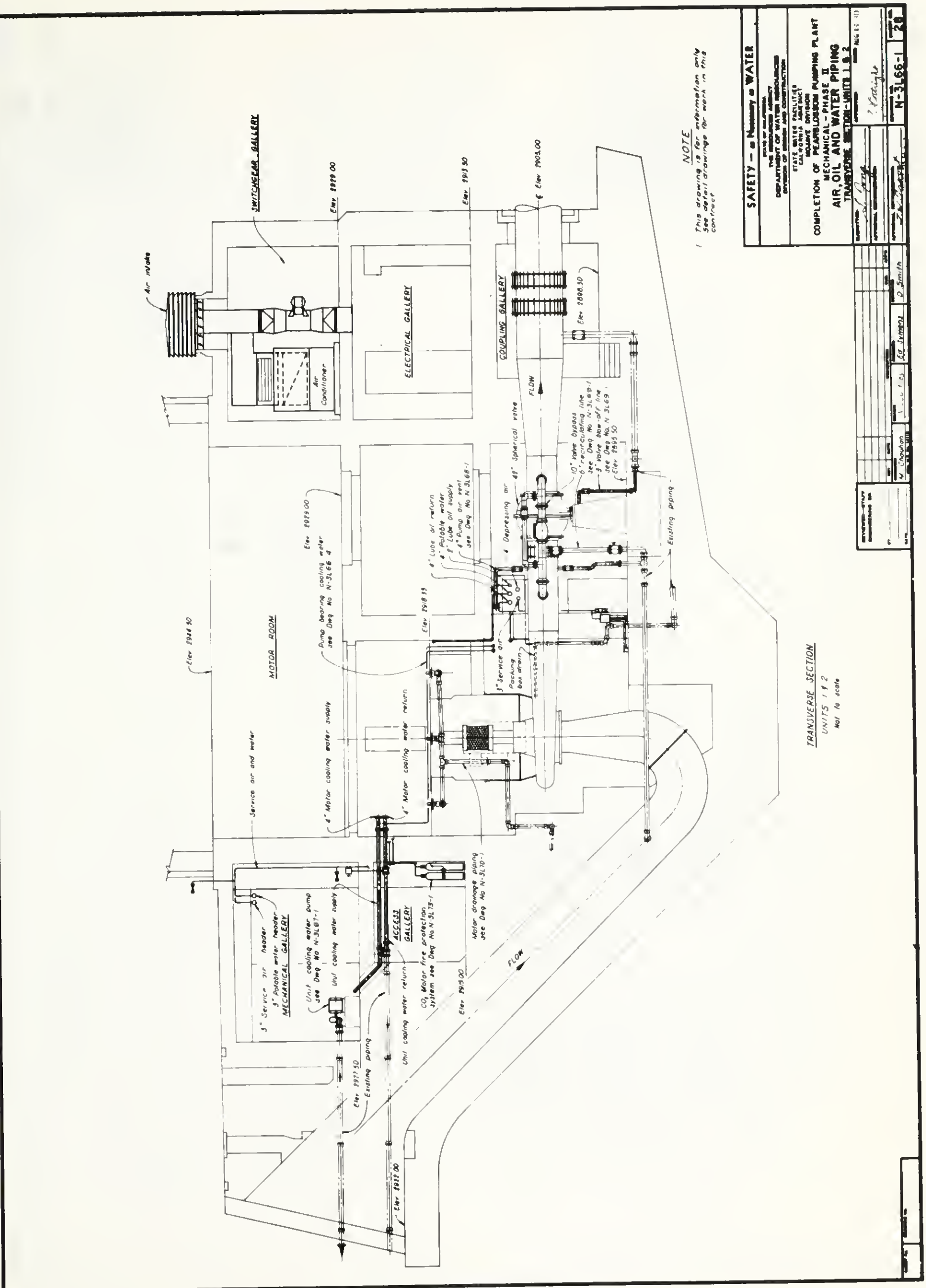

Figure 692. Air, Oil, and Water Piping

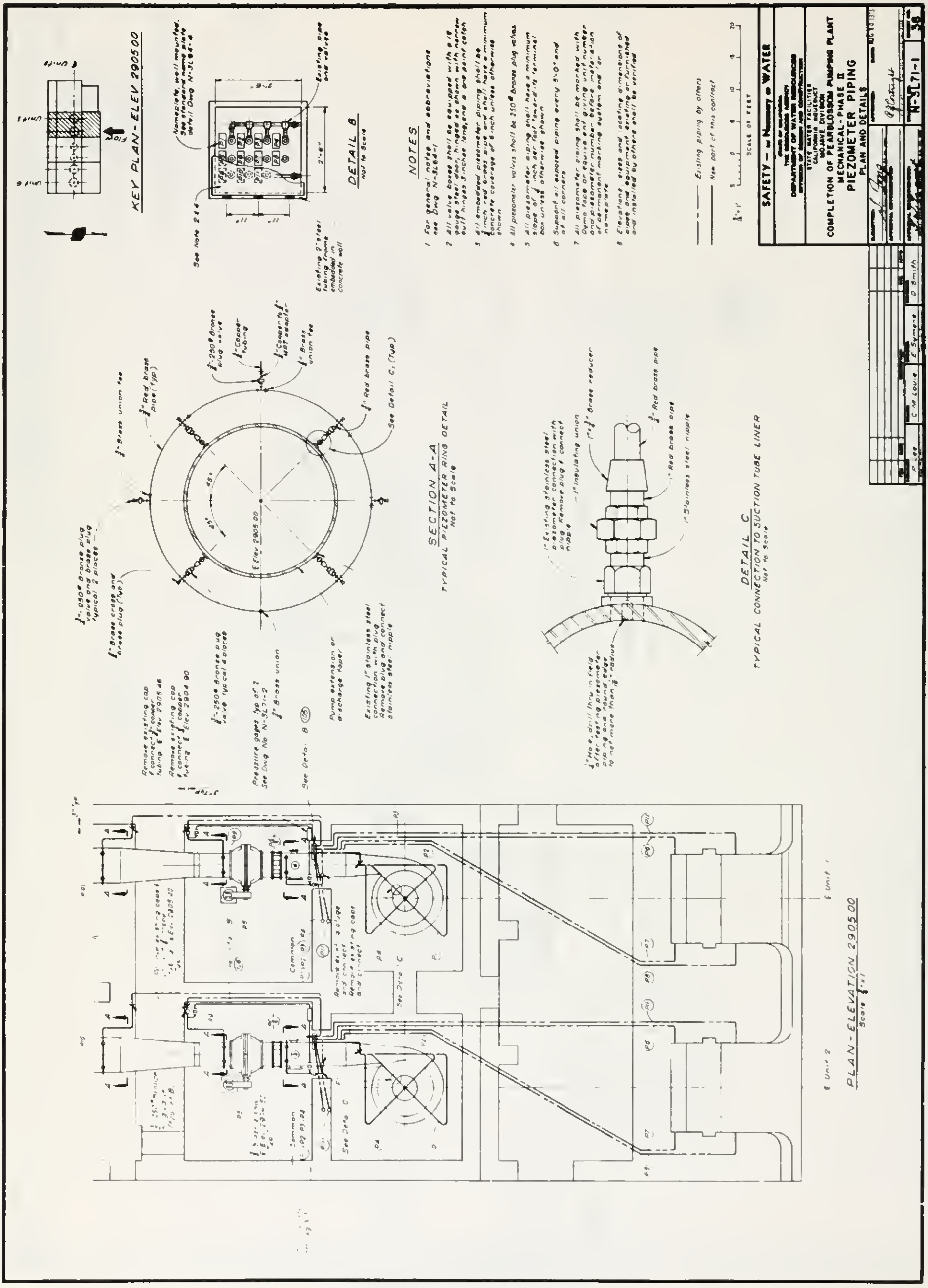

Figure 693. Piezometer Piping

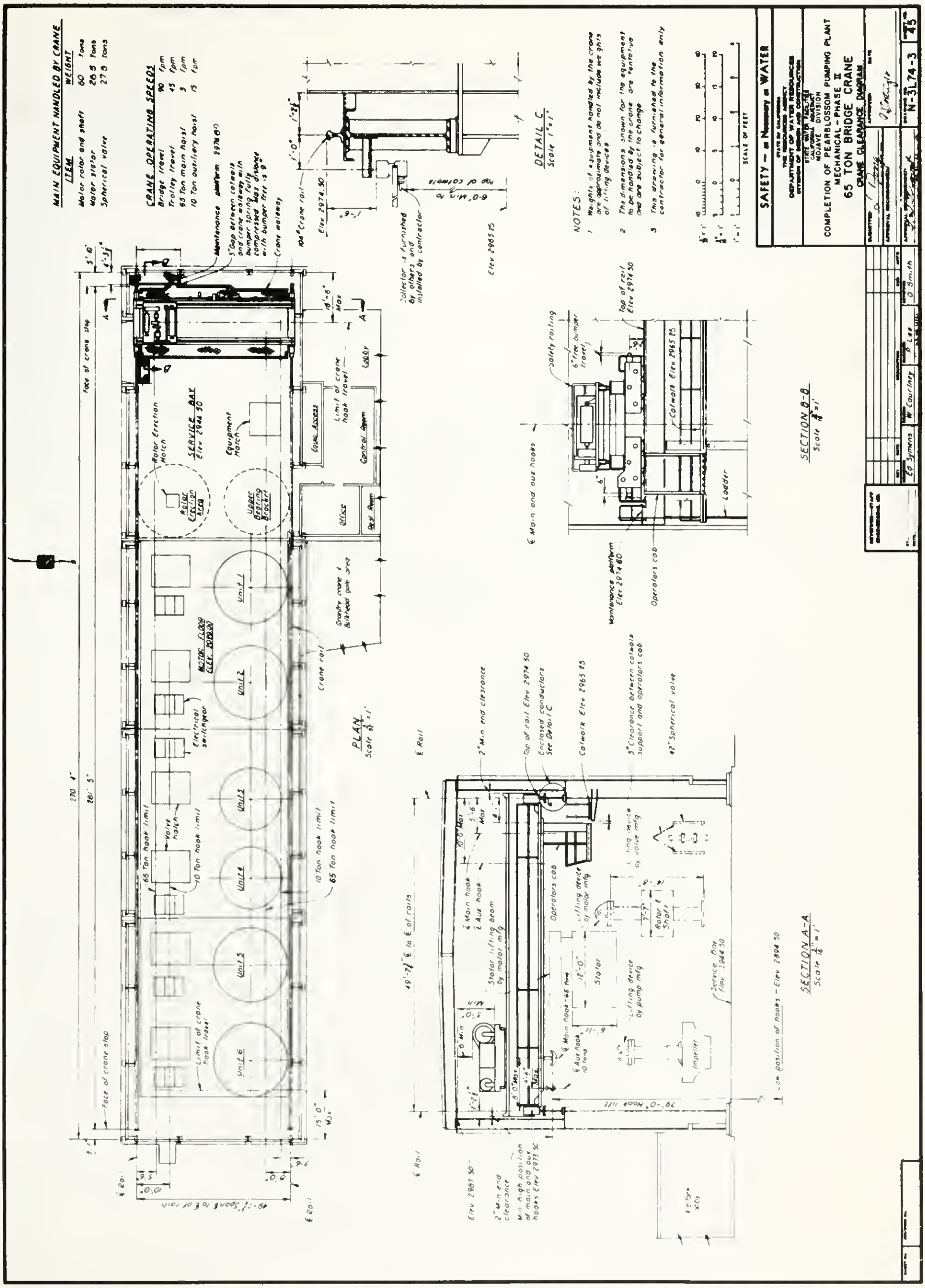

Figure 694. 65-Ton Bridge Crane

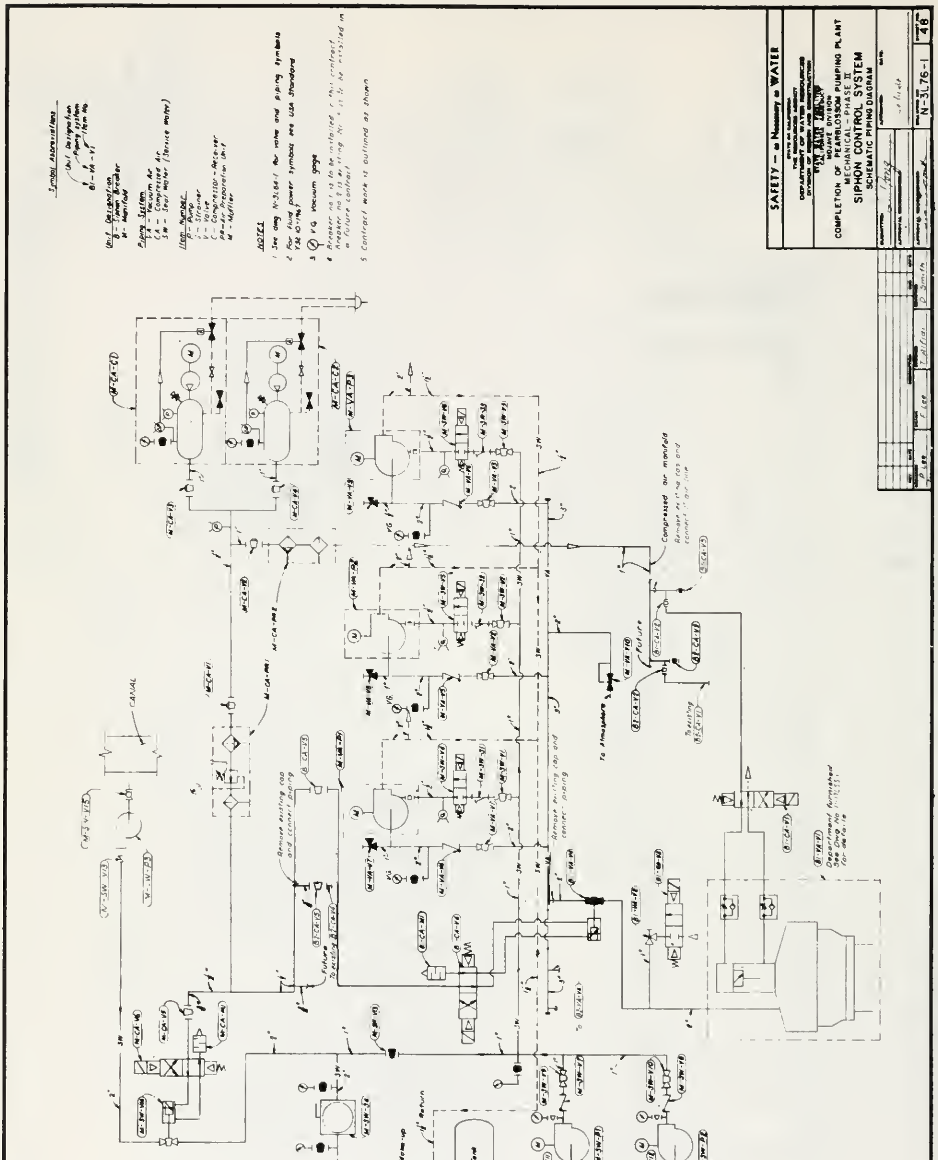

Figure 695. Siphon Control System

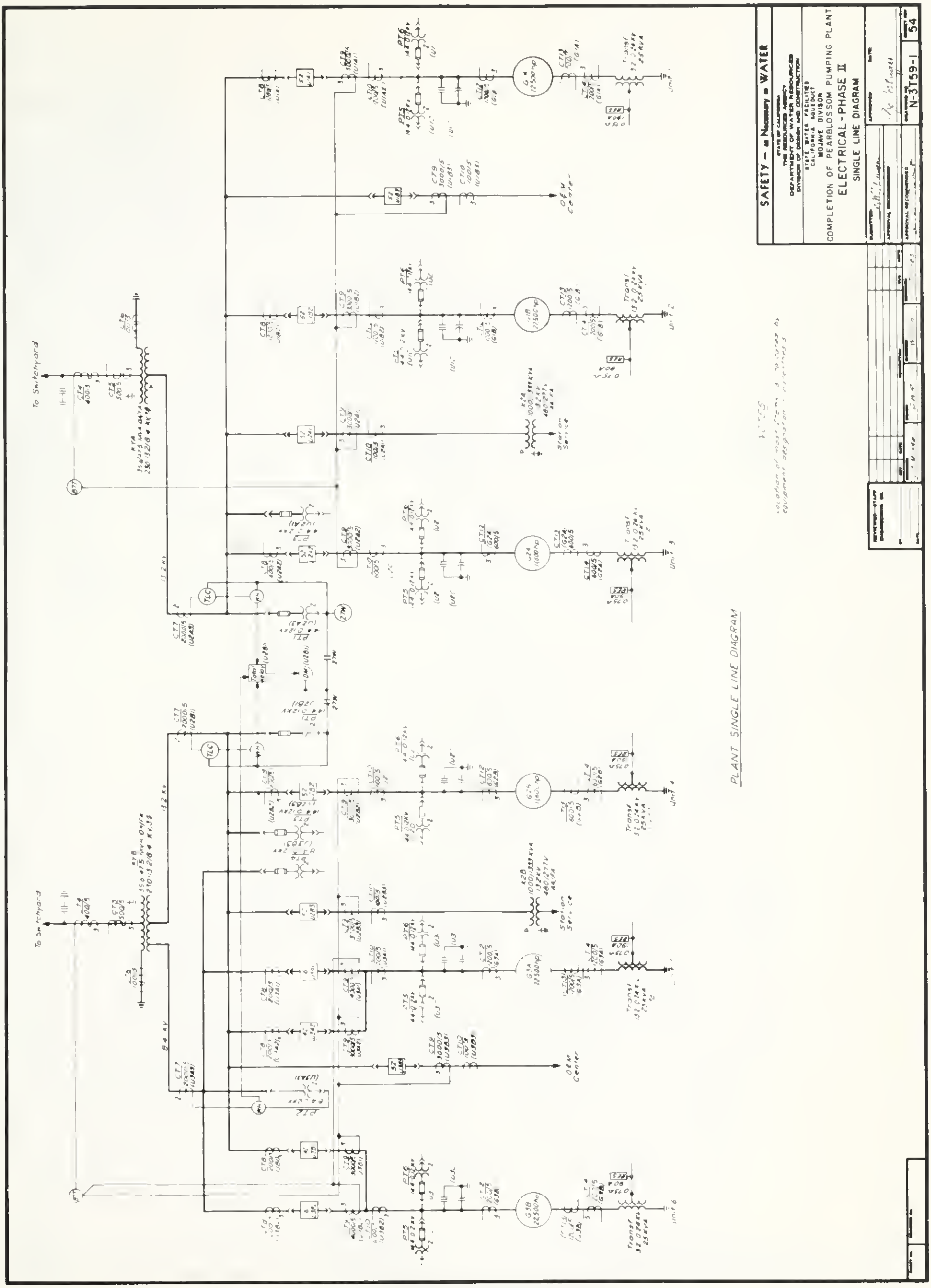

Figure 696. Plant Single-Line Diagram

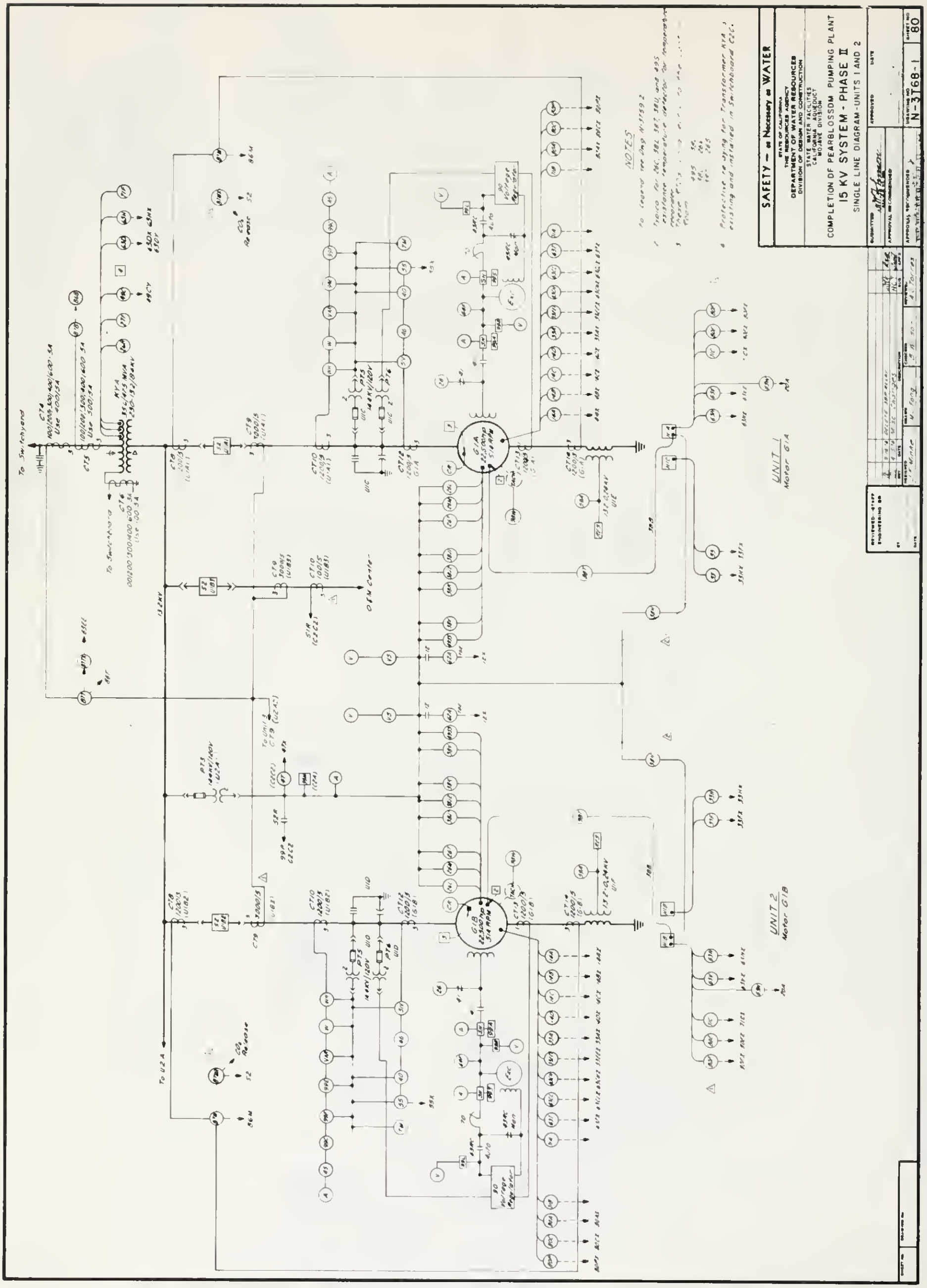

Figure 697. 15-kV System—Single-Line Diagram

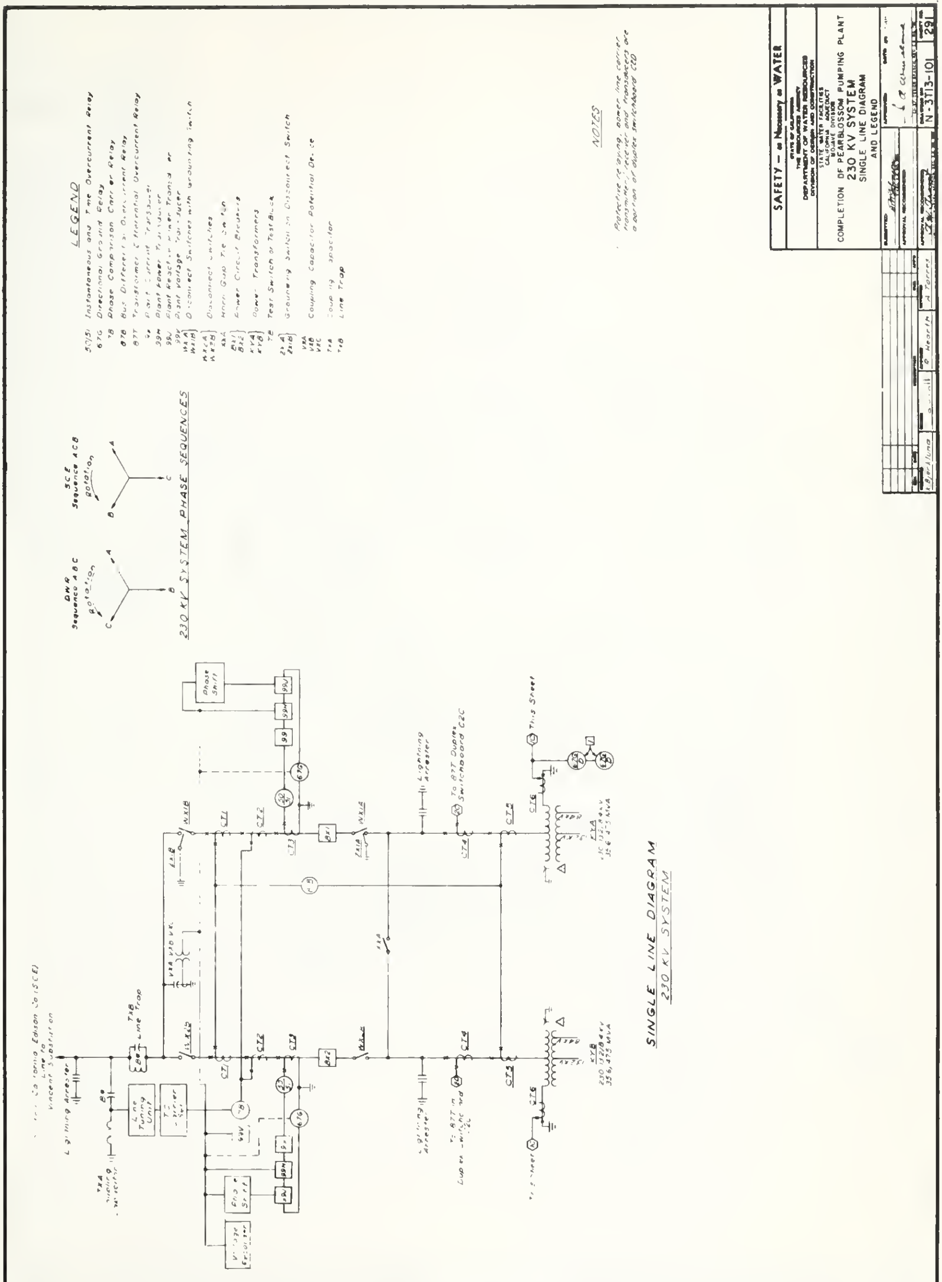

Figure 698. 230-kV System—Single-Line Diagram

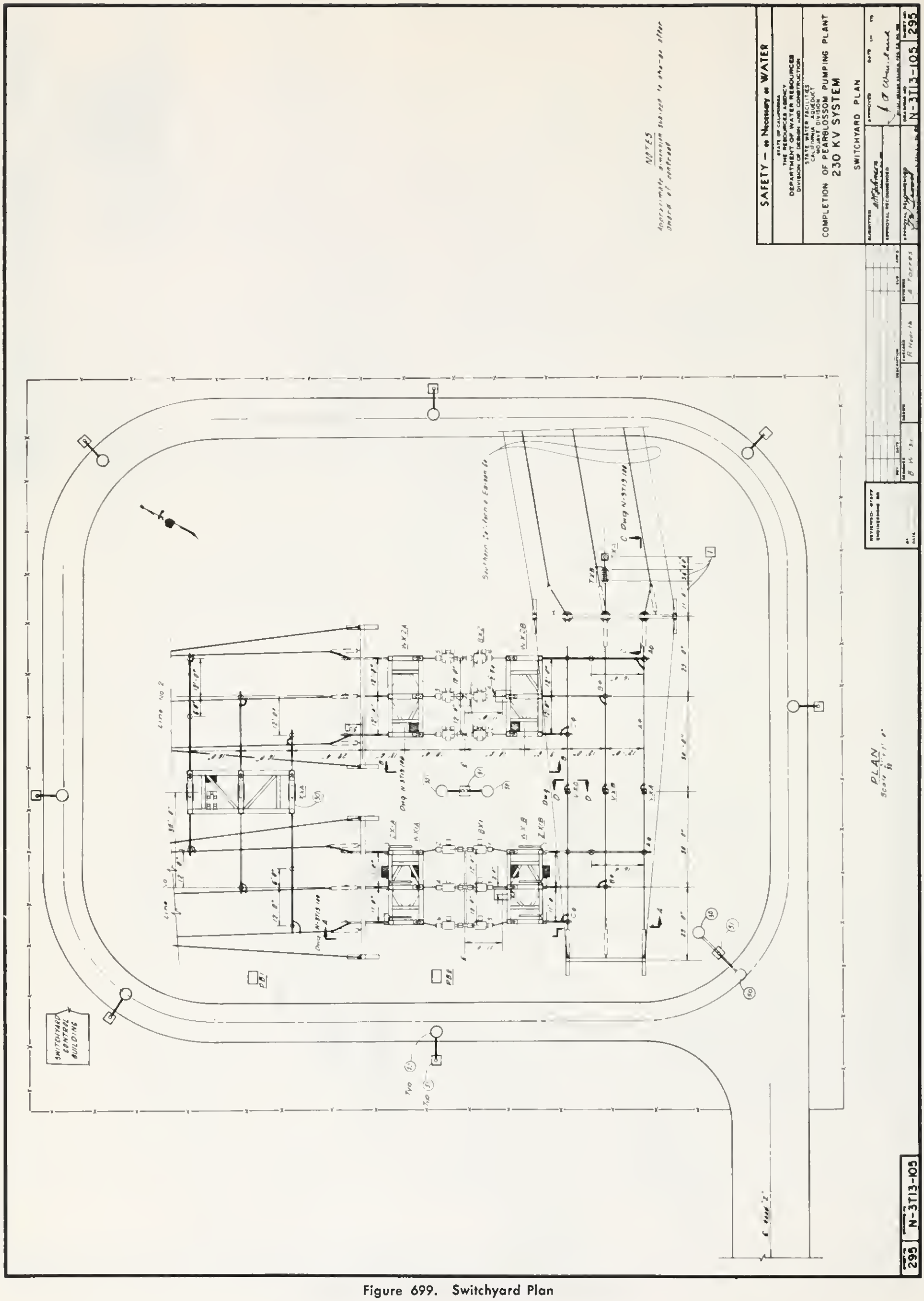

Figure 699. Switchyard Plan

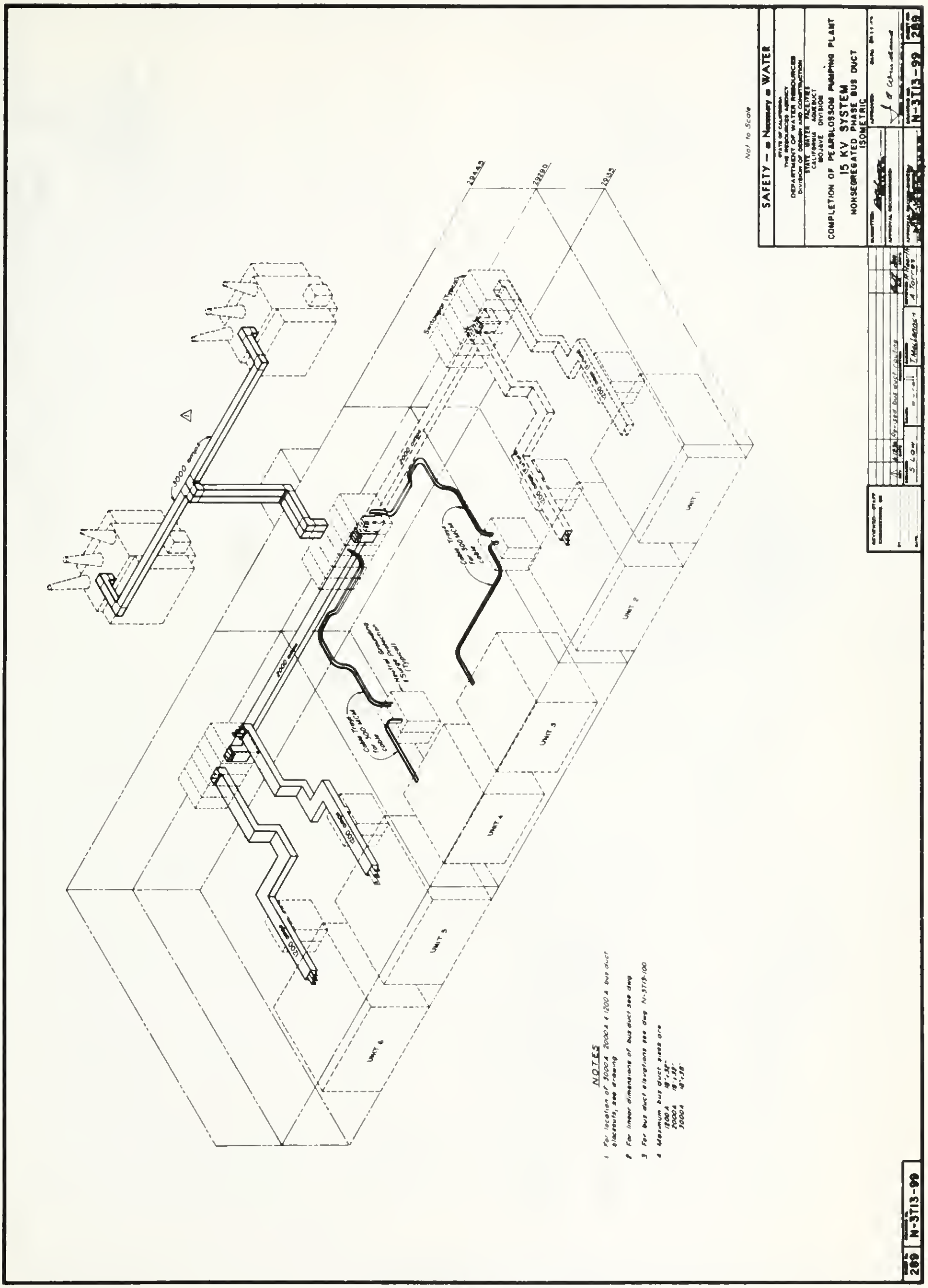

Figure 700. Nonsegregated-Phase Bus Duct

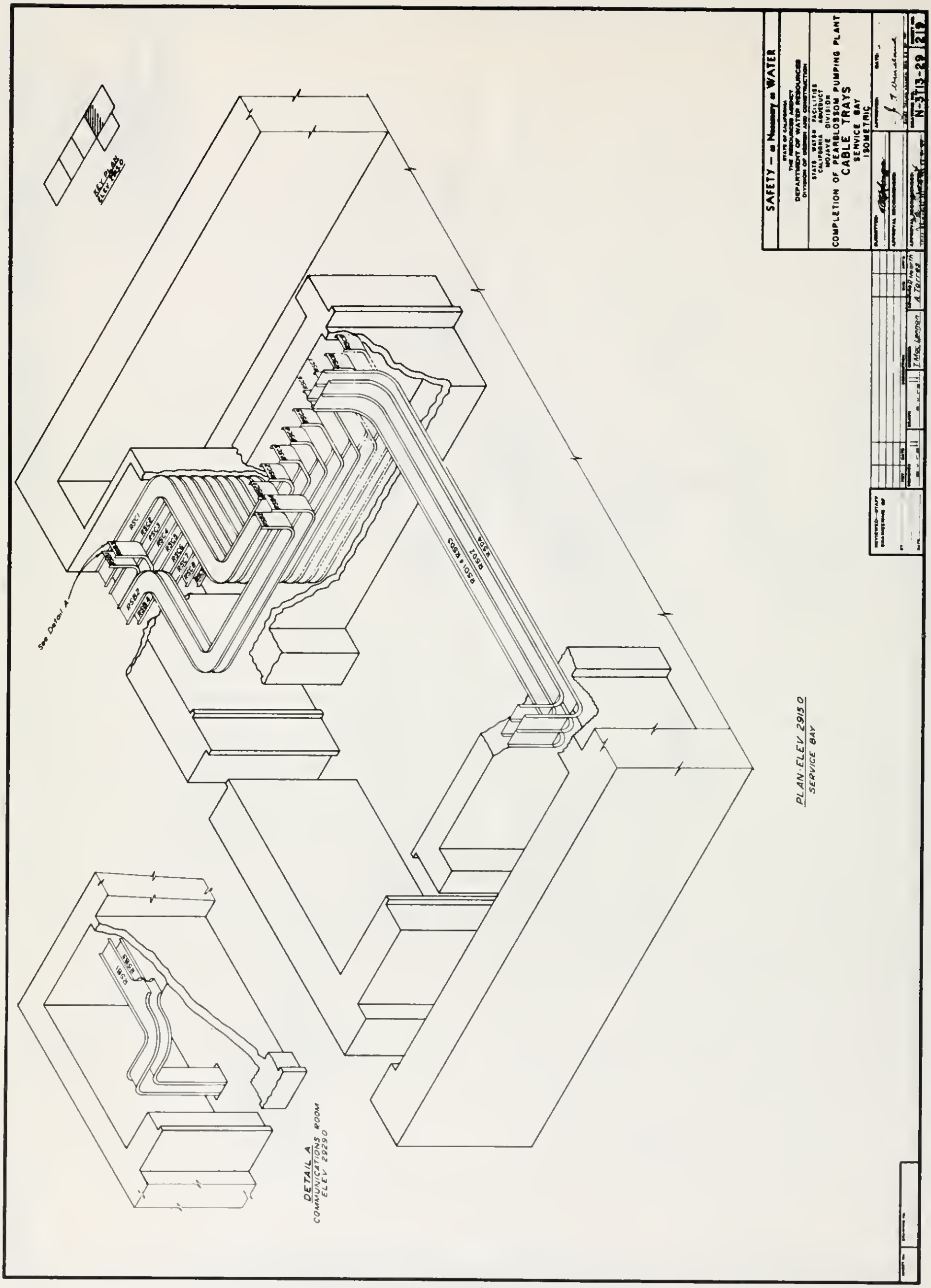

Figure 701. Cable Trays

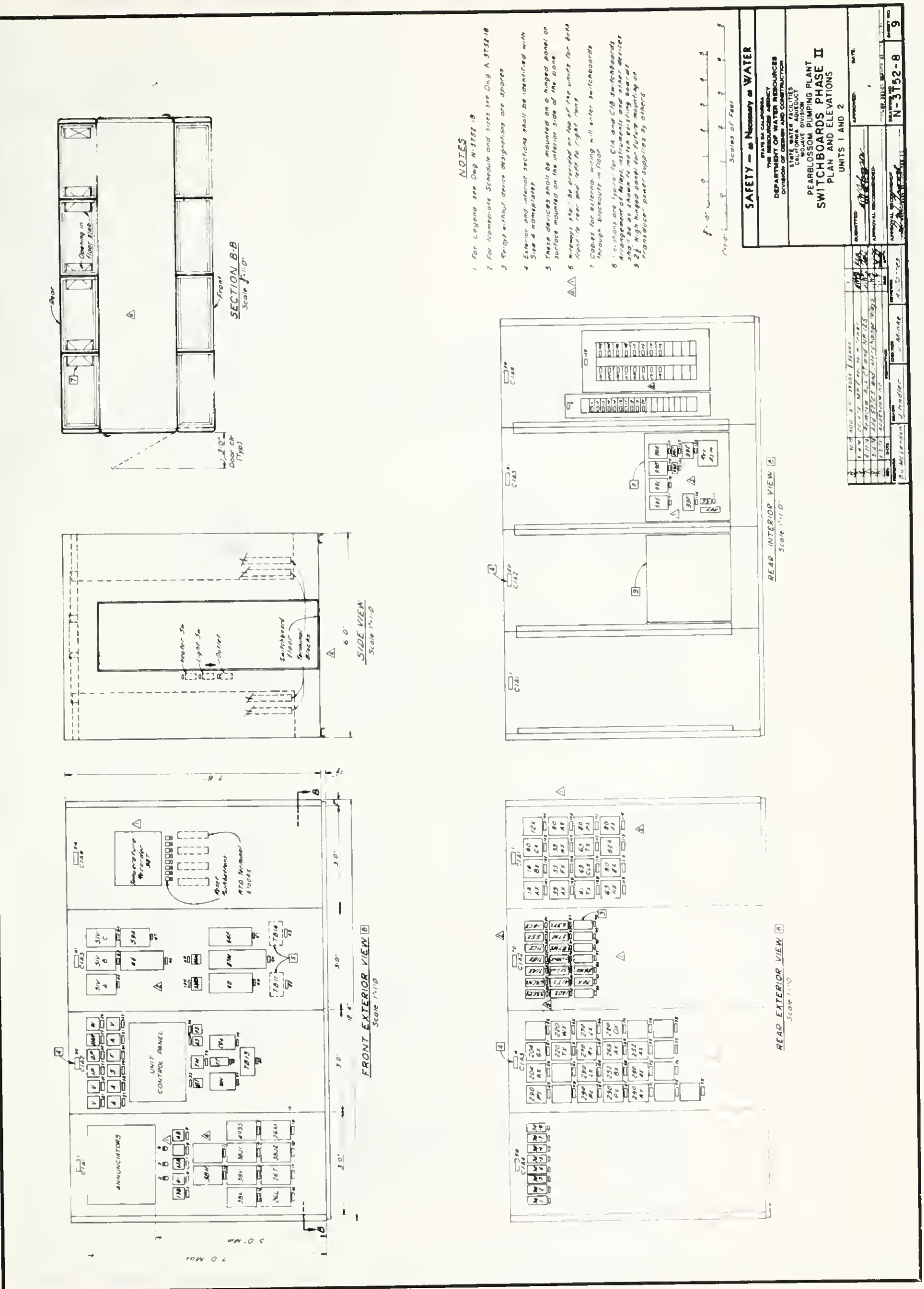

Figure 702. Switchboards—Plan and Elevation

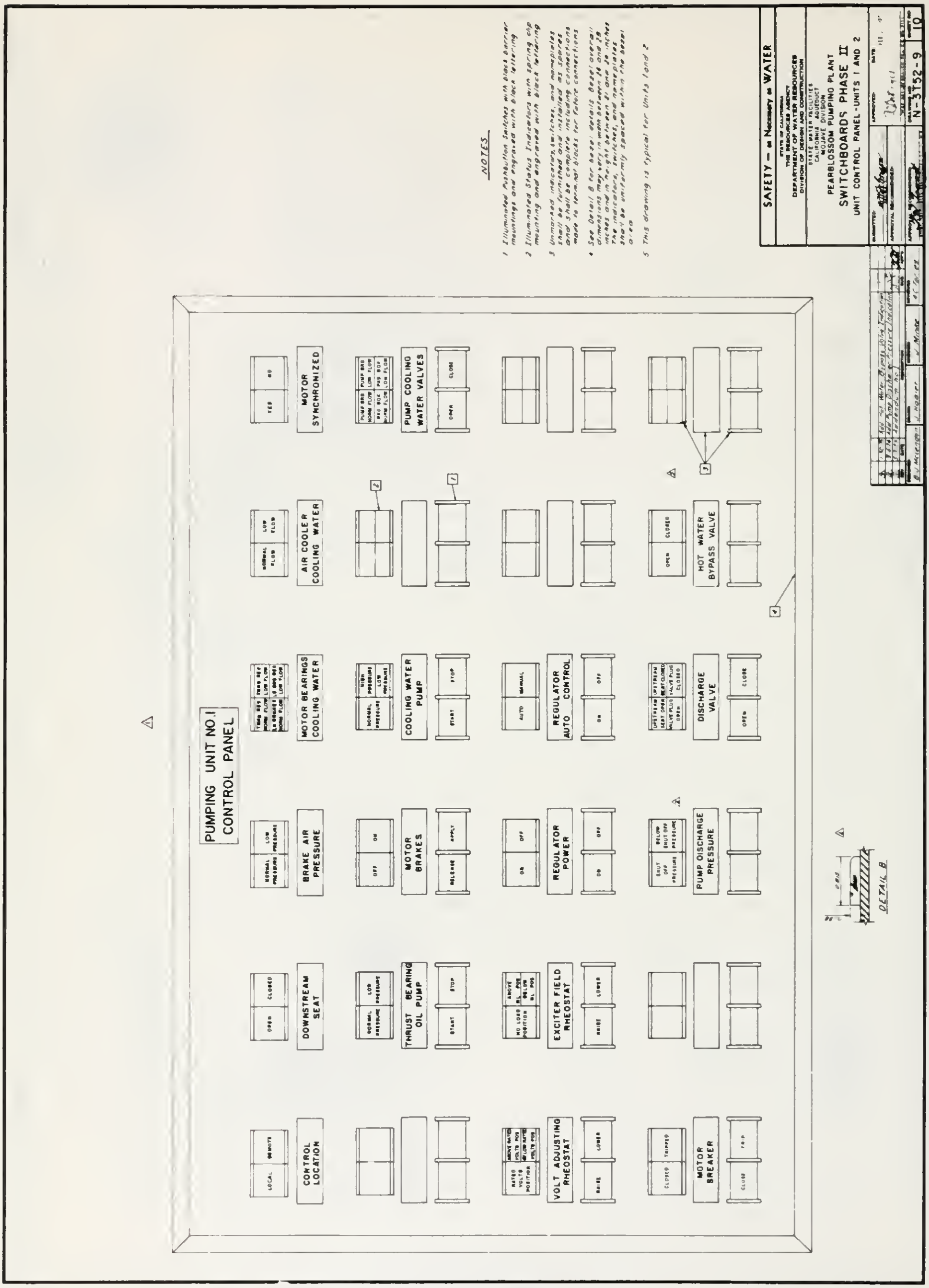

Figure 703. Unit Control Panel

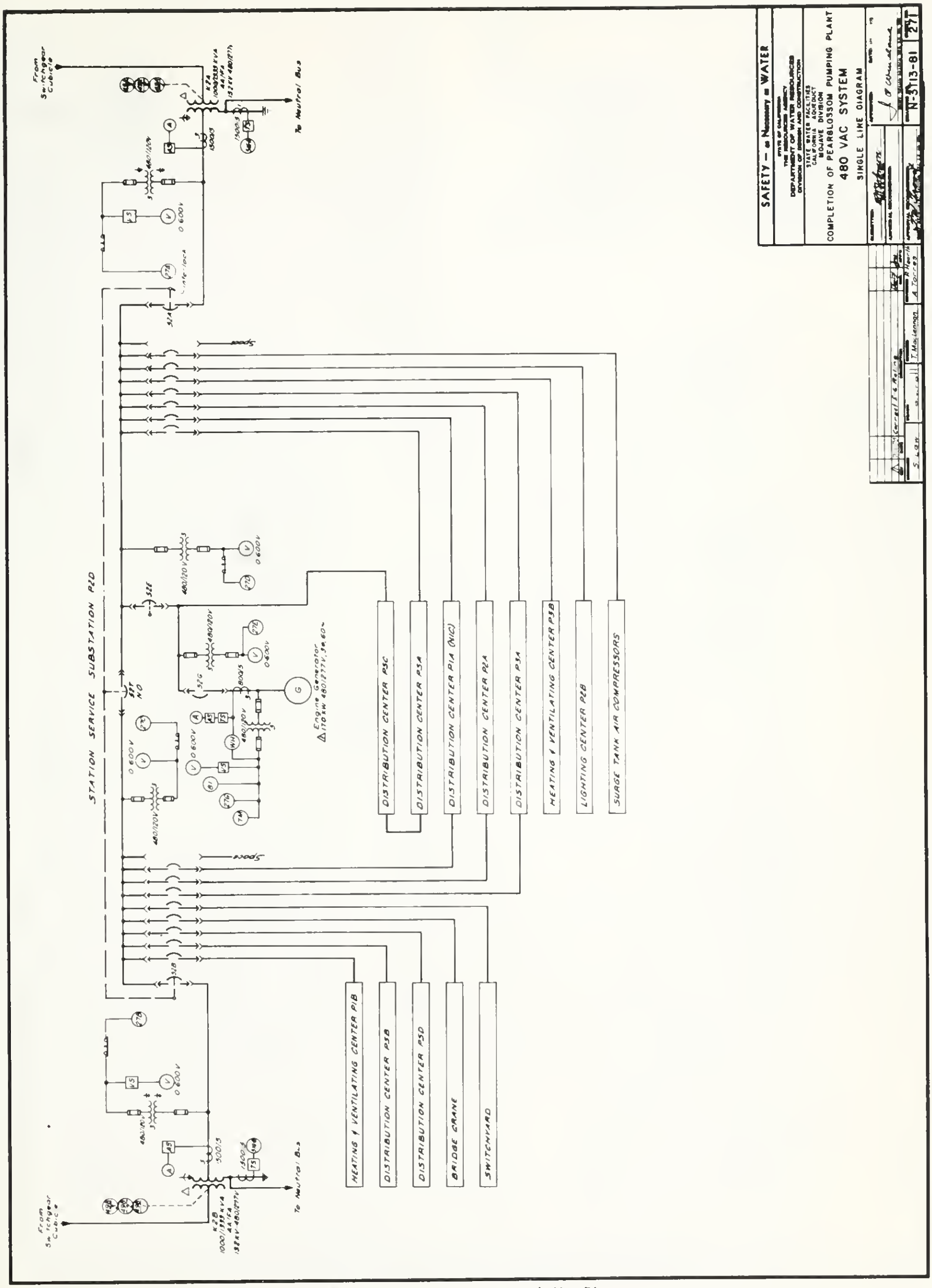

Figure 704. 480-VAC System—Single-Line Diagram

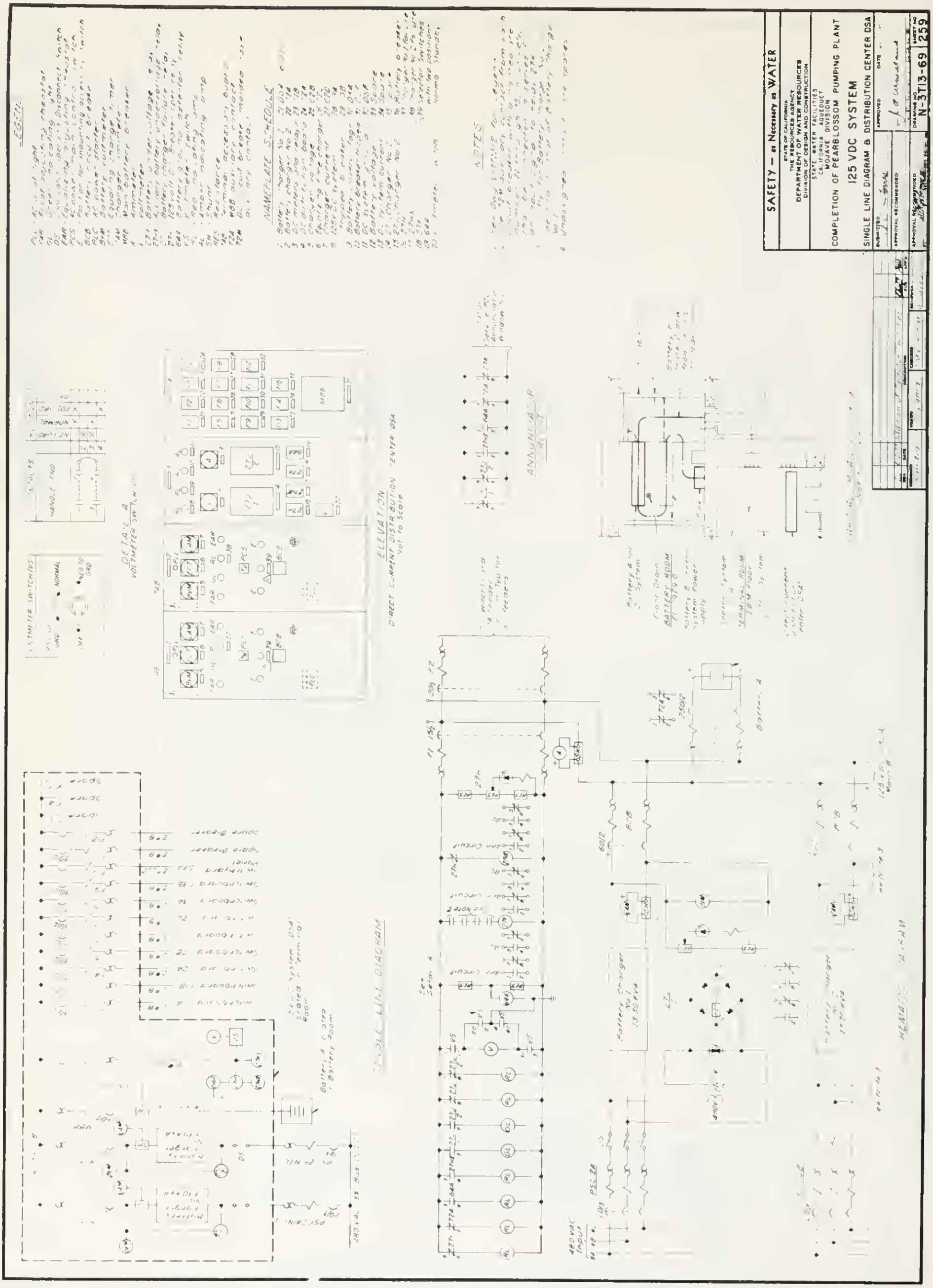

Figure 705. 125-VDC System—Single-Line Diagram

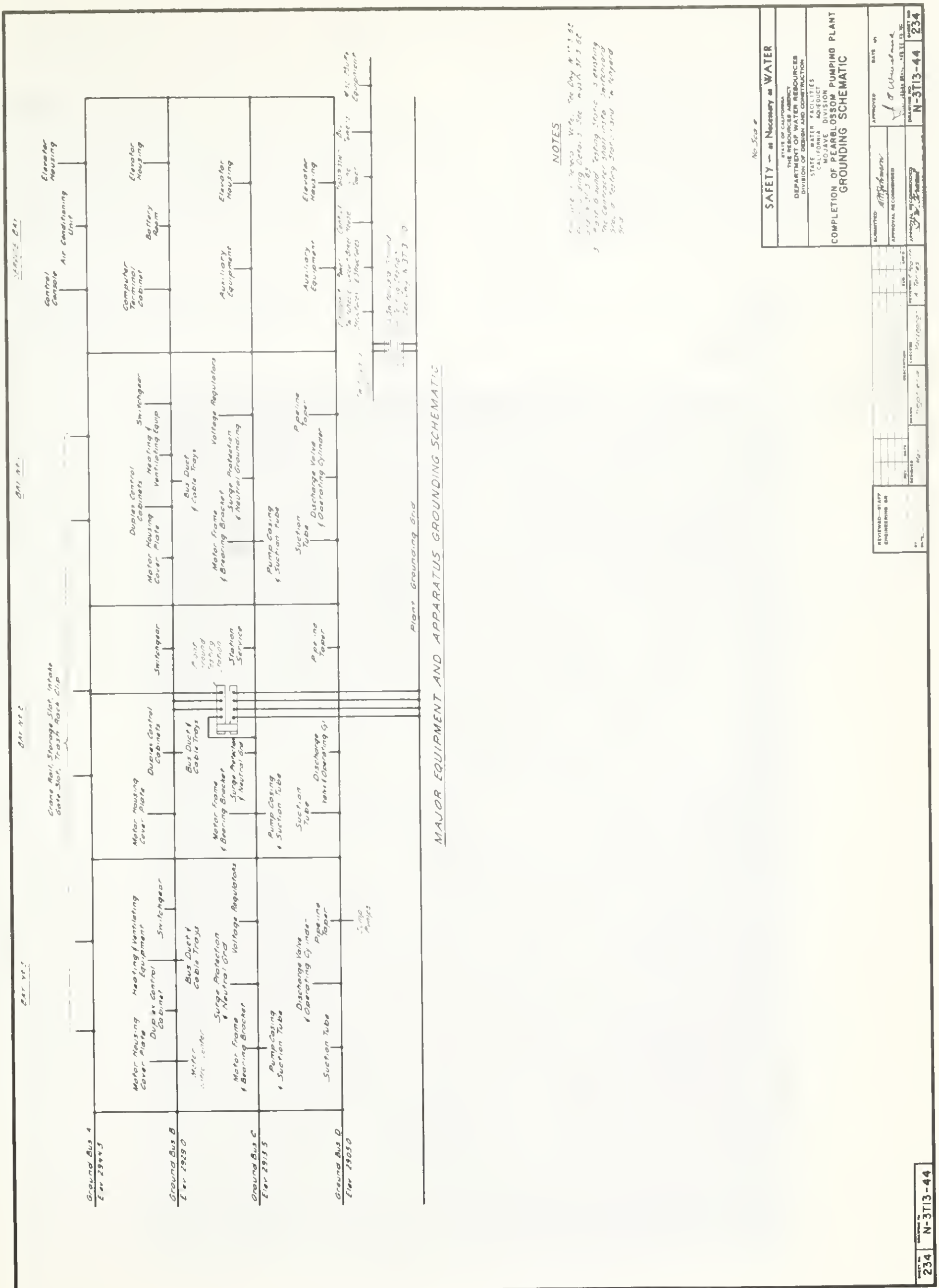

Figure 706. Grounding Schematic

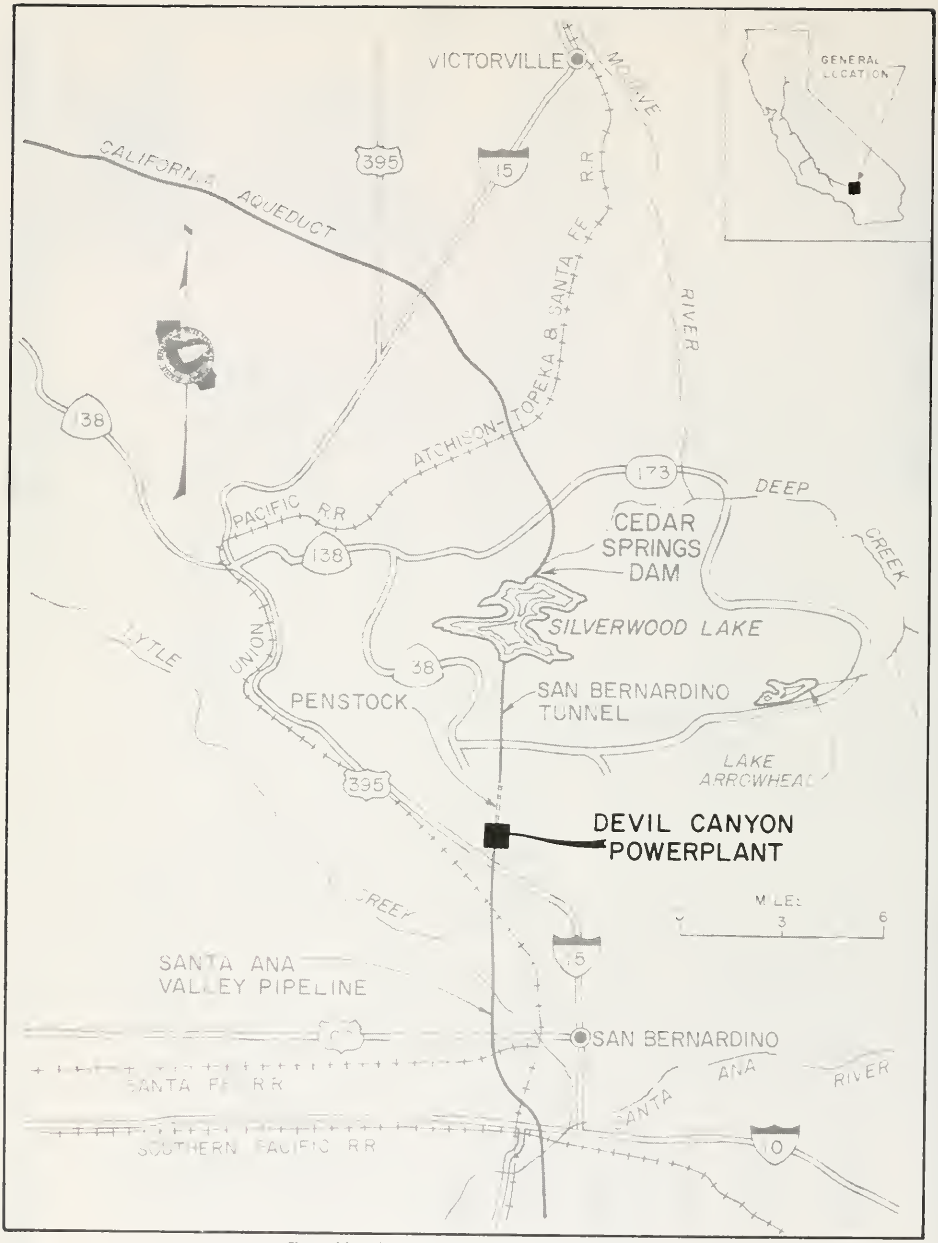

Figure 707. Location Map—Devil Canyon Powerplant

CHAPTER XV. DEVIL CANYON POWERPLANT

General

Location

Devil Canyon Powerplant is located approximately 5 miles north of San Bernardino, California. The nearest major road is Interstate Highway 15. The plant is situated near the mouth of Devil Canyon at the southern base of the San Bernardino Mountains (Figures 707 and 708).

Purpose

Devil Canyon Powerplant is a power recovery facility that generates electrical power from the available flow through the Santa Ana Division of the California Aqueduct. It receives water from Silverwood Lake through the San Bernardino Tunnel and a 6,749-foot-long penstock. The plant discharges into a small afterbay, which distributes the water through individual pipelines to the contracting water users. Water which is not delivered to water users at this location continues on through the Santa Ana Valley Pipeline to Lake Perris, the terminal reservoir on the Aqueduct.

Description

Devil Canyon Powerplant (Figure 709) has two

Figure 708. Aerial View—Devil Canyon Powerplant

generating units with a total capacity of 1,200 cubic feet per second (cfs). The estimated annual output is 1.003 billion kilowatt-hours. Each unit has a 54-inch shutoff valve in the penstock immediately upstream of the unit. Provisions were made during construction of the existing structure for the addition of a third unit with a capacity of about 827 cfs. This additional unit will require an extension to the existing structure and construction of a separate penstock.

The two initial units are vertical-shaft, single-runner, impulse turbines directly connected to synchronous generators. The two units have a power generation output of 119,700 kilowatts. Water is supplied to these units by a 114-inch-diameter steel penstock.

A concrete-lined flood channel diverts Devil Canyon Creek around the powerplant site (Figure 710).

Representative drawings are included at the end of this chapter.

Geology

Areal Geology

Geologic structure of the southern part of the San Bernardino Mountains is dominated by the San Andreas fault and its numerous subparallel branches. In the vicinity of Devil Canyon, the San Andreas and Santa Ana faults form boundaries between significantly different rock types.

In general, north of the San Andreas fault, the Mountains are composed of interlayered crystalline igneous and metamorphic rocks. The Pelona schist is found south of and within the San Andreas fault. Granite occurs between the San Andreas and Santa Ana faults. Location of the plant was restricted by the faulting. The plant is north of both faults, but the Santa Ana fault crosses the afterbay.

Site Geology

Bedrock in the Devil Canyon area is metamorphic rock, including gneiss, marble, and quartzite, and ig-

Figure 709. Interior View

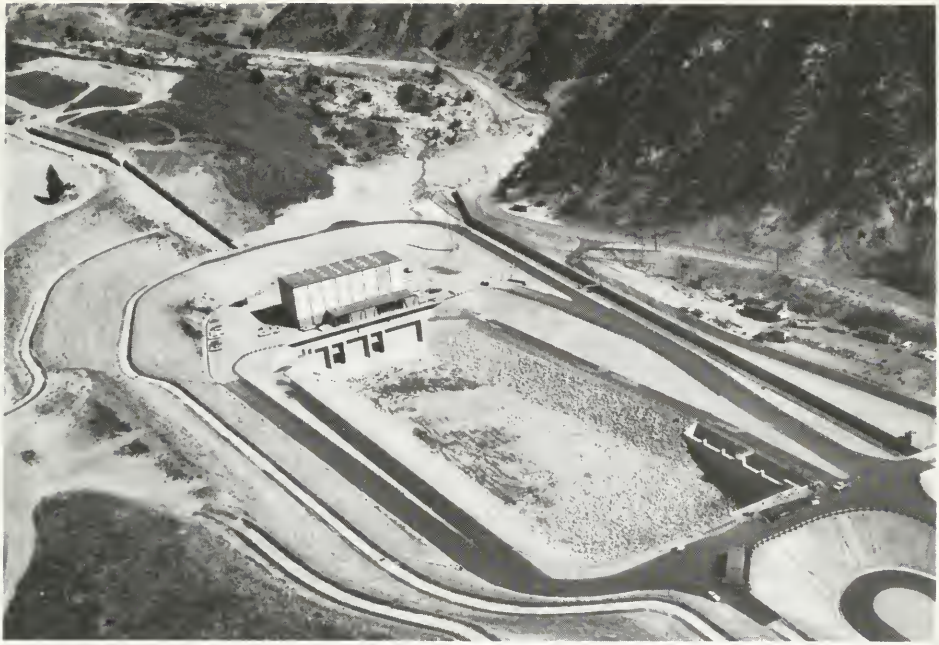

Figure 710. Exterior View

neous rocks ranging from granite to gabbro. Where the rock is faulted, crushing and shearing have formed gouge and breccia. The foundation of the Powerplant is in the diorite gneiss, a metamorphic rock.

Between the Santa Ana and San Andreas faults at Devil Canyon, massive granite occurs in a band 600 feet wide. The granite is highly fractured and sheared. However, the granite is relatively competent, and a bold outcrop forms a steep slope on the west side of Devil Canyon between the two faults.

Along the margins of Devil Canyon, these older crystalline rocks are overlain by terrace deposits. The floor of Devil Canyon has been covered with stream deposits of sands, gravels, and boulders.

A trench 17 feet wide and 15 feet deep was excavated in Recent alluvium at the flood channel inlet. Bedrock was exposed at both ends of the trench but was not found in the middle. An impervious clay membrane was placed in the trench to serve as a ground water cutoff.

Ground water in the vicinity of the flood channel posed a threat to the afterbay clay membrane if the afterbay were to be emptied. A perforated drain was installed along the east side of the afterbay to relieve excessive ground water pressures.

The turnout structure foundation is sandy gravel (Recent alluvium) except for the extreme west end, which is moderately weathered granite.

Excavation of the afterbay revealed fault gouge and decomposed metamorphic rock on much of the side slopes. Because this material is friable and susceptible to erosion, it was covered with riprap.

Rock at the west wing wall of the plant was adversely affected by shear zones and seeping water. Overexcavation and backfilling was necessary in the shear zones in the foundation rock of the plant.

The support footings for the penstock consist of Recent alluvium, Older alluvium, and diorite gneiss. The materials encountered in most areas provide adequate support for the structure. A few areas required overexcavation and some areas required riprap for erosion protection.

A fault zone was exposed where the penstock crosses Devil Canyon Creek. The fault zone material consists of gray clay gouge, serpentine, crushed limestone, and crushed diorite gneiss, with large blocks of hard limestone and strongly weathered diorite gneiss. The anchor block foundation at the base of the penstock is weathered diorite gneiss. This material is competent and adequate for the structure.

Geologic Exploration

Five exploration trenches were excavated to supplement the drilling and geophysics to determine foundation conditions for the powerplant, afterbay, and turnout structures. The exploration helped determine the width and location of the Santa Ana fault zone so that structures could be placed on the most competent rock in the area.

Seismic Instrumentation

Instrumentation was installed to monitor seismic activity in the vicinity of Devil Canyon since this area is considered one of the most seismically active areas in the State. Four precise geodetic quadrilaterals were established near Devil Canyon to detect creep along the active faults. One strong-motion seismograph and seven seismoscopes were installed in the area.

Before the plant was constructed, the strong-motion seismograph was triggered several times by small local earthquakes. However, the seismoscopes did not record the shocks, and the intensity was too small to provide significant information. The Department of Water Resources is continuing to monitor the precise measurement grid.

A tiltmeter was installed on the terrace deposits immediately west of the plant site with a special leg across the Santa Ana fault. No tectonic movement was detected by the tiltmeter and it was dismantled.

Seismicity

The San Andreas fault zone is approximately 1 mile wide in this area, with the recent traces coinciding with the northeasterly edge of the zone. Crushed rock and gouge of the Santa Ana fault crosses the afterbay and is about 360 feet wide.

Rupture of facilities by displacement along a fault and shaking caused by an earthquake are considered possibilities. A maximum of 20 feet right lateral displacement and 3 feet vertical displacement are possible on the San Andreas fault, in the opinion of the Department of Water Resources Consulting Board for Earthquake Analysis. Should such a movement take place, it most likely would occur along tthe most recent trace of the fault. Such displacement also could occur on the Santa Ana fault (Figure 711).

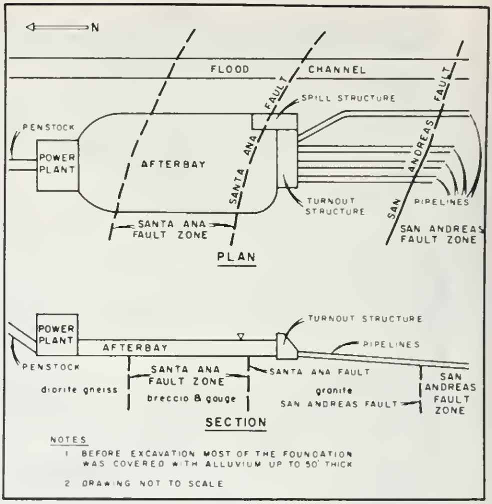

Figure 711. Geologic Plan and Section

Civil Features

Preliminary Studies

During the planning stage for this power development, several alternative routes and systems were investigated. These alternatives included a two-plant scheme, a three-plant scheme, a single underground plant, and a single surface plant system. Additional studies were conducted comparing the performance of Francis turbines and impulse turbines, and one unit versus two units. A single surface plant with two impulse turbines was adopted.

Site Development

The plant site was determined on the basis of powerplant optimization studies and by weighing the relative significance of distance from the fault zone, quality of rock in the foundation, size of excavation, and location of the flood channel facilities for Devil Canyon Creek.

The bowl for the Powerplant was excavated in the hillside on the west side of the canyon. The finished level work area around the plant is approximately 435 feet in the east-west direction and 240 feet in the north-south direction. This area provides room for the plant, switchyard, parking, and access around the facility. The side slopes of the bowl are 2:1 with a 20-foot berm at 40-foot vertical intervals. Drainage from the bowl is collected by a system of ditches and downdrains and discharged into the afterbay.

A flood channel bypasses floodflows past the plant site. The maximum peak runoff expected from the Devil Canyon Creek watershed is 8,000 cfs. Conservative safety factors and other design considerations were adopted to assure maximum protection for the plant. The channel begins slightly north and east of the plant. A 140-foot-long inlet transition collects the incoming storm waters and conveys them past the plant and afterbay in a concrete-lined rectangular channel. This channel, approximately 1,450 feet long with a 500-foot-long energy dissipator at the lower end, is 30 feet wide and varies from 10 to 25 feet in depth. A maximum depth of water in the intake transition occurs during large flows. To assure that seepage or percolation from this high water poses no danger to the plant, a sloped, 10-foot-thick, clay membrane extends across the entire opening of the inlet transition down to bedrock.

The only access to the Powerplant is located on the east side of the canyon. Therefore, it was necessary to construct a bridge across the flood channel. This bridge is a rigid concrete structure which utilizes a specially reinforced wall and floor slab section of the flood channel for foundation support.

Plant Structure

The plant is a reinforced-concrete monolith, with no joints other than construction joints. It is 162 feet long, 104 feet wide, and 63 feet deep at maximum depth and contains the coupling gallery, valve pits, turbine runners, spiral case, needle valves, tailraces, and other electrical and mechanical equipment necessary for operation of the plant.

During excavation for the plant, a zone of heavily sheared rock was discovered at the southwest corner of the foundation. This corner of the structure was heavily reinforced and cantilevers over this weak foundation zone.

The coupling gallery is located upstream of the valve pits and contains the penstock articulation spools. Access to this gallery is through a watertight door. In case of penstock rupture at the spools, this door prevents flooding of the main plant. Water will drain through two grated floor openings into the tailrace below.

The tailrace, in addition to passing the discharge from the turbines to the afterbay, also provides a working area for removing the turbine runner. To allow removal of the runner, a steel bulkhead gate has been provided to close off the tailrace while dewatering the unit. The gate is made in two sections to facilitate ease of handling.

Substructure. The structural arrangement was developed around the two 44-foot-diameter unit cores and was influenced by the desire to minimize plant width. The large cores are the main support for the downstream superstructure columns and are the interior supports for the floor framing system. The framing system is monolithic with the generator support structures on each floor.

Design of the substructure allowed for the future addition of a third unit without jeopardizing the structural integrity of the existing building. The west wall of the substructure, on both floors, consists of heavy framing with an 18-inch panel wall that can be removed to extend the building. Likewise, the first panel section of the west wall is readily removable to provide space for the tailrace of a third unit. The west frame of the superstructure has adequate structural strength to permit continuation of the crane girder into the addition (Figure 712).

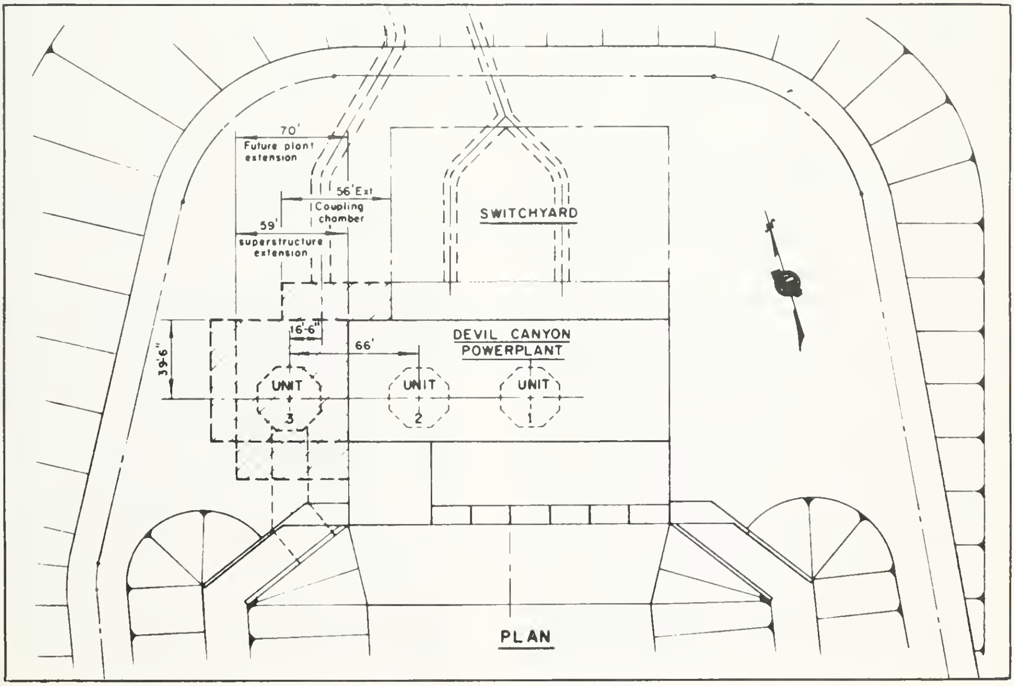

Figure 712. Future Expansion of Plant

Superstructure. The superstructure extends the entire length of the plant and houses the service area and the generator floor. The front and rear decks are exposed. Since the substructure is one monolith, the superstructure has no expansion joints. Steel frames are exposed to accentuate the individual frames for architectural reasons.

Nine similar rigid frames form the superstructure. Frames 3 through 9 have a support bracket for an L-frame. The L-frame, located on the south side, forms the supporting structure for the facility wing to the superstructure. This wing houses the elevator, entrance area, control room, mechanical room, washroom, office, and kitchen.

Thirty-five feet above the main floor there are haunches on both columns of each frame. These haunches support the crane girder and rail for the 225-ton-capacity bridge crane. The bridge crane travels the entire length of the superstructure to provide service to the erection area and generator floor.

Structural Instrumentation

During construction of the Powerplant, 9 soil stress meters, 20 concrete stress meters, and 2 hydrodynamic pore pressure cells were installed at various locations. Readings from these instruments are monitored on an established time schedule, then analyzed to determine if there has been any changes in stresses or pressures.

Three strong-motion accelerometers have also been installed in the plant: one in the foundation material, one at the top of the substructure, and a third approximately midway between the two.

Waterways

Penstock. The 6,749-foot-long penstock begins immediately downstream of the San Bernardino Tunnel and conveys water to Devil Canyon Powerplant.

This penstock is an aboveground steel pipeline of varying diameter. It begins at the south portal of the San Bernardino Tunnel and ends at the turbine shutoff valve in the Powerplant.

The outlet from the San Bernardino Tunnel is a 12-foot 9-inch-diameter steel pipe containing a roll-out section and ending with a bifurcation. The western branch of the bifurcation is bulkheaded and will be used for the future penstock to Unit No. 3. The other branch is 9 feet - 6 inches in diameter and ends at a 114-inch, butterfly, emergency, shutoff valve.

Downstream of the 114-inch butterfly valve, the penstock is 9 feet - 6 inches in diameter with a design capacity of 1,200 cfs. It reduces in diameter in 6-inch increments. After reduction to an 8-foot diameter near the Powerplant, it branches and enters the plant in two 6-foot lines. The easterly branch discharges into Unit No. 1, and the westerly branch will serve Unit No. 2.

Inside the plant, the two penstock branches pass through a coupling chamber where the typical, articulated, short-spool assembly, previously described in Chapter I of this volume, is installed as a segment of each penstock pipe.

The exposed penstock is composed of 40-foot pipe lengths supported by a ring girder and bearing assembly on each end. At each pipe joint, a pair of ring girders rest on a single concrete pier. A sleeve-type coupling joins the pipe units and provides flexibility. The upstream, ring-girder, bearing assembly of each pipe length has an expansion bearing which can slide on its support block. Teflon pads are used for the sliding surfaces. The downstream, ring-girder, support bearings are fixed with bolts.

Hydraulic thrusts at the bends along the aboveground penstock alignment are resisted by concrete anchor blocks. Normal seismic loads were considered during design of the supports, but this condition did not govern.

The tunnel outlet bifurcation and the first bend are anchored by prestressed anchor tendons. These were designed to carry a load of 300 kips each. This anchorage method is the least costly and best suited to the site conditions.

The penstock pipe is buried and encased at two locations: once where it crosses the channel of Devil Canyon Creek, and again for a distance of approximately 310 feet next to the Powerplant. Concrete encasements on the buried pipe support the earth load and act as anchors to resist thrusts developed at bends and the bifurcation.

Design pressure for the penstock is the maximum static pressure plus dynamic pressure due to closing the turbine needles. The dynamic pressure at the plant is about 10% over the static pressure. Design head on the penstock varies from 348 feet at the tunnel portal to 1,576 feet at the Powerplant.

The penstock and manifolds were designed for the following loading conditions and corresponding allowable stresses:

1. For normal condition including dead load, water load, and transient pressures, the design stress is 0.5 yield stress (f_y) of the material.
2. For filling and emptying the penstock, the allowable stress is 0.65 f_y.
3. For normal conditions and an earthquake force, the allowable stress is 0.75 f_y.
4. For normal condition and test pressure, the allowable stress is 0.75 f_y.

Steel pipe and manifolds were designed using 100% efficiency for welded joints. To assure 100% joint efficiency, the following tests were made during fabrication:

1. All full-penetration welds were 100% radiographed.
2. All fabricated sections were hydrotested to 150% of the design head.

Steel plate material for the penstock shell and bifurcation reinforcement is ASTM A537, Grade A, normalized. The ring girders were fabricated from ASTM A36 material, except that ASTM A441 was used on spans greater than 40 feet in length.

The penstock shell plates vary from ½-inch to $1\frac{3}{16}$-inch thickness, and a 4-inch crotch plate was required at the lower bifurcation.

Afterbay. The flow from the Powerplant discharges directly into the afterbay. The afterbay fulfills the following functions:

1. It provides an open water surface for hydraulic control at the intakes of multiple pipelines which distribute the flow to the water users' system and the Santa Ana Valley Pipeline.
2. It provides a crossing of the Santa Ana fault. Damage of this "open" afterbay would be relatively easy and quick to repair.
3. It provides a minimal amount of storage for mismatching of the inflow and outflow.

The afterbay is an earthen reservoir, approximately 550 feet long, 250 feet wide, and 15 feet deep. The south end of the afterbay is formed by the concrete headworks for the various turnouts. An overflow spillway is located in the southeast corner. Any spill from the afterbay will be dumped into the flood channel. The west side of the reservoir is formed by excavation into the hill, while the east side is retained by an embankment. Portions of the bottom and the east embankment are protected by riprap.

Mechanical Features

General

The mechanical installation includes two turbines, turbine shutoff valves, governors, crane, and auxiliary equipment. Unit No. 1 turbine is installed and operating. Unit No. 2 turbine, governor, and valve are under contract and are scheduled for operation in 1976.

Chapter I of this volume contains information on the mechanical equipment and systems for this plant which are common to other plants in the State Water Project. Information and descriptions which are unique to this plant are included in the following:

Selection of Units

Both Francis- and impulse-type turbines were considered for this plant. The final decision to use the impulse turbine was based on the following factors:

1. Highly reliable.
2. Reduced penstock pressure rise. Needle timing may be extended without affecting unit speed rise.
3. Capability of bypassing water through the unit with the deflectors in place.
4. Selection of 2, 4, or 6 needle operation permits a wide range of flow with high unit efficiency.

Hydraulic Transients

Hydraulic transient criteria were:

1. Simultaneous rejection of 115% of rated plant generating load at maximum head.
2. Simultaneous load acceptance of all units at minimum head.
3. Speed rise limited to approximately 30% by the deflectors.

In order to reduce the pressure rise and consequently the cost of the lengthy high-pressure penstocks, a relatively long governor time of 90 seconds was adopted for this plant. This timing will limit the waterhammer surge to 10% above the static pressure of the system. This results in the optimum design since system load and frequency control, as normally considered, are not possible due to the small afterbay and the long start (acceleration time) of the pipelines to Lake Perris and the downstream water users.

An impulse turbine is ideally suited for this type service, because the discharge through the unit is not influenced by a change in runner speed. Further, the overspeed can be controlled by the deflectors, while the discharge is slowly reduced by the needles.

Field Tests. Higher than expected penstock pressures were encountered when, preparatory to start-up testing of Unit No. 1, the turbine shutoff valve was tested by the manufacturer. The purpose of this test was to verify the satisfactory closure of the valve against maximum needle discharge with the deflectors in place. This had to be accomplished first before the turbine manufacturer's representative would permit the unit to be started. During closure, the gauges on the control panel were observed to reach 680 pounds per square inch (psi), a pressure rise of 10%, the maximum design pressure for simultaneous needle closure of two turbines; closure of only one valve should have produced less than half this rise. A subsequent review revealed that the hydraulic operator on the valve had been inadvertently set at the minimum specified closing time; it was further suspected that the manufacturer's valve closure curves submitted for transient studies were in error.

Subsequently, in February 1973, the Department's hydraulic transient tests on Unit No. 1 were performed. Inspection of the resultant oscillograms produced by the now fully instrumented valve test showed the manufacturer's predicted valve closure curves (discharge v. stroke) were, in fact, in error. Flow was reduced by the rotating valve plug much more rapidly in the mid-stroke range than was expected. Also, flow through the open seat was approximately 10% of full flow, much higher than anticipated. To reduce pressure rise to the acceptable level, valve closure time was adjusted to 240 seconds for the plug followed by seat closure in 12 seconds.

After all adjustments were made, a 115% rated load rejection produced a pressure rise of 5% over static pressure with a speed rise of 30%, well within the design criteria for a single unit. Final tests showed all systems operated satisfactorily and confirmed that adding a second unit to the penstock could be safely accomplished.

The surge tank, at the head of the penstocks, which serves San Bernardino Tunnel, will be tested upon completion of installation of Unit No. 2. A completely instrumented test was considered unnecessary with only one unit operational. Since the surge chamber is designed to accommodate flow for the ultimate three-unit powerplant capacity, and one unit produces minimal surging, the oscillograph traces for the penstock were judged adequate to verify proper operation for the interim period.

Figure 713. Turbine Pit

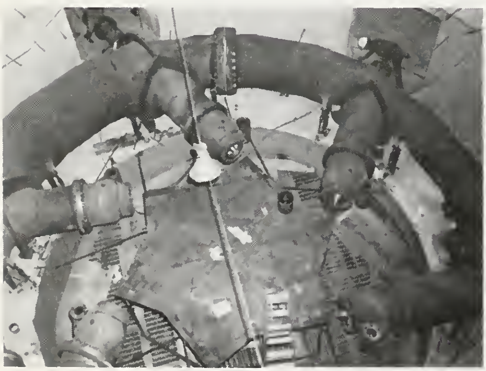

Figure 714. Turbine Scroll Case and Nozzles

Equipment Ratings

Turbine	
Manufacturer:	Unit No. 1—Baldwin-Lima-Hamilton Corp. Unit No. 2—Escher Wyss
Type:	Impulse, six-nozzle, vertical-shaft
Horsepower:	81,000 @ 1,357 feet
Head:	1,368 to 1,433 feet
Speed:	277 rpm
Maximum Efficiency:	90.5%
Turbine Shutoff Valve	
Manufacturer:	Unit No. 1—Baldwin-Lima-Hamilton Corp. Unit No. 2—Escher Wyss
Type:	Spherical, double-seated
Size:	54 inches
Design Pressure:	720 psi
Operating Time:	4 minutes
Operating System Pressure:	2,300 psi
Penstock Valve	
Manufacturer:	Yuba Industries, Inc.
Type:	Butterfly
Size:	114 inches
Design Pressure:	120 psi
Operating Time:	1 minute
Operating System Pressure:	2,300 psi
Governor	
Manufacturer:	Unit No. 1—Baldwin-Lima-Hamilton Unit No. 2—Cheston Co.
Type:	Cabinet-actuator
System Pressure:	350 psi
Servo Capacity: (Needles and Deflector)	275,200 ft-lbs
Full Needle Stroke:	90 sec./60 sec. cushion
Full Deflector Stroke:	6.5 sec.
Crane	
Manufacturer:	Crane Hoist Engineering and Mfg. Co.
Type:	225-ton, double-trolley, electric, overhead, traveling, bridge
Main Hoist:	112.5 tons
Auxiliary Hoist:	25 tons
Span:	53 feet - 1 inch

Turbines

The turbines are vertical-shaft, single-runner, six-jet, impulse type and were designed for direct connection to a synchronous generator operating at 277 rpm (Figures 713 and 714). The setting of the centerline of the wheel is at elevation 1,942 feet. The maximum afterbay water surface is at elevation 1,934 feet, which provides ample clearance against flooding of the wheel. The units are capable of producing a wide range of power at high efficiency (from 10,000 horsepower at 88% efficiency with two nozzles to 90,000 horsepower at 90% efficiency with six nozzles).

The runner is of the integrally cast type, fabricated from chrome alloy cast steel for protection against cavitation and pitting (Figure 715). The turbine wheel pit provides for removal of the runner from below by means of a transfer car. Six nozzles supplying water to the turbine runner are each equipped with a servomotor-operated needle to control flow (Figure 716). Each nozzle is equipped with a jet deflector, which is operated by means of a deflector servomotor (Figure 717). The needle and deflector servomotors are balanced by helical springs so that total needle closure and total deflection, respectively, can be achieved in the event of failure of governor oil pressure. A braking nozzle assists for final shutdown.

Turbine Shutoff Valves

Each unit is provided with a 54-inch shutoff valve (Figure 718). It is the spherical-type, double-seated, hydraulic cylinder-operated and was designed to sustain the maximum transient pressure without exceeding allowable design stresses.

Figure 715. Turbine Runner

Figure 717. Jet Deflector

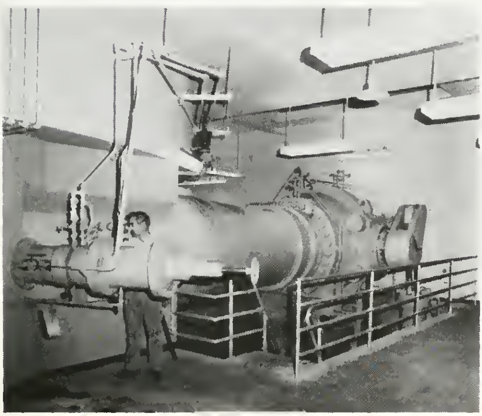

Figure 716. Turbine Needle Servomotor

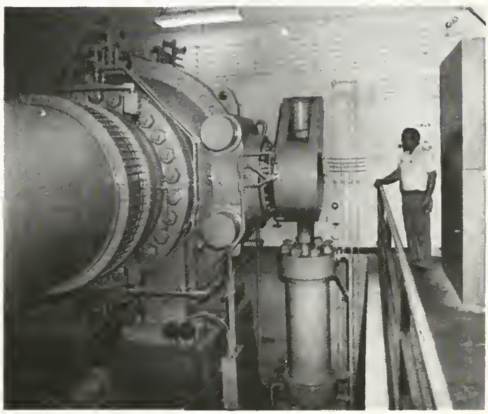

Figure 718. 54-Inch Turbine Shutoff Spherical Valve

The valve has an electrohydraulic actuating and control system (Figure 719). Each seat is separately controlled and operated by water from the pressure side of the valve. The valve and controls were designed for normal opening and closing and for emergency closure under full head. The hydraulic system consists of 2,300-psi, nitrogen-charged, piston-type accumulators; sump; pumps; valves; piping; and controls required for operation.

The operating system was designed with as many fail-safe features as practicable. The design provided for an automatic sequencing unit with feedback and interlock features to avoid operator error. Numerous provisions and back-up devices were installed to prevent accidental opening of the valve during the construction period and periods of maintenance when the spiral case man-door may be opened.

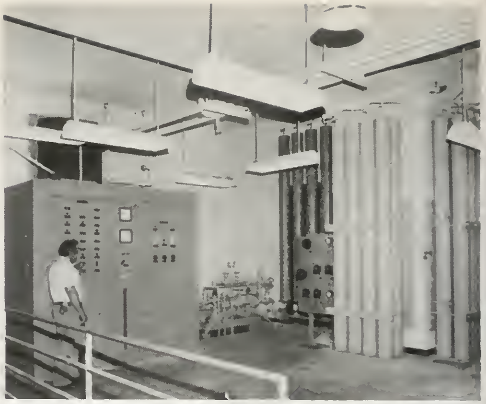

Figure 719. Spherical Valve Control Cabinet

Penstock Valve

The penstock valve is located at the end of San Bernardino Tunnel just downstream of the surge chamber at an elevation approximately 1,150 feet above the Powerplant (Figure 720).

The normally open valve is used for dewatering the penstock for downstream repair and maintenance. It is designed for emergency closure against flows up to 3,300 cfs in the event of seismic damage to the penstock. Emergency closure is initiated by actuation of a velocity trip mechanism. This mechanism was calibrated during hydraulic transient tests to permit adjustment for higher flows when the second unit is installed on the penstock.

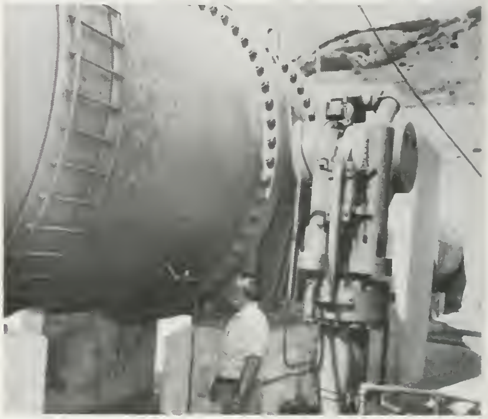

Figure 720. 114-Inch Penstock Butterfly Valve

The valve is designed to be opened under a balanced head which is obtained by means of a 10-inch bypass valve. Operating power for the penstock valve and bypass is provided by a nitrogen gas-driven piston accumulator system. The 2,300-psi hydraulic system is capable of one opening and two closing cycles before recharging is required by the pumps.

Governors

Each unit has an electrohydraulic, oil-pressure, cabinet-actuator-type governor designed for speed regulation and control of the turbine. The governor has an electrically driven speed-responsive element directly connected to the pilot valve for operation of the master needle relay valve. Movement of the master needle relay valve positions the remaining five slave needle relay valves. Jet deflectors are actuated by speed-sensing control linkage whenever the needle movement is too slow to control the speed rise (Figures 721, 722, and 723).

In addition to manual, local, and remote controls, the governor has an electrically operated speed-adjust mechanism which receives its signal from the afterbay control system for automatic control of the units.

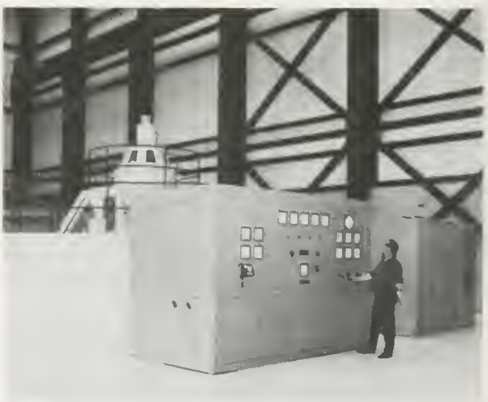

Figure 721. Governor Control Cabinet

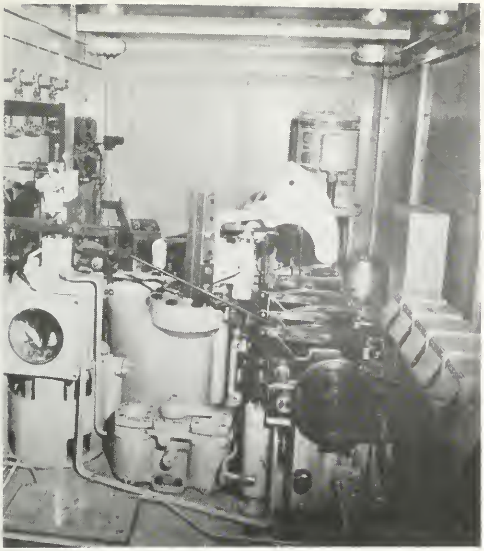

Figure 722. Governor Control Cabinet—Interior

Figure 723. Governor Accumulator Tank and Piping

Equipment Handling—Crane

This powerhouse has a 225-ton bridge crane, sized for the larger future unit, for installation and maintenance of plant equipment. It has two trolleys, each with a 112.5-ton main hoist and a 25-ton auxiliary hoist. When handling the generator rotor, the two 112.5-ton hoists operate in unison with rotor suspended on a lifting beam.

Auxiliary Service Systems

The auxiliary service systems in the plant are described in Chapter I of this volume with the following exception:

Afterbay Water-Level Control. Precise regulation of flow by the turbines was imperative to avoid overtopping or draining the afterbay due to its small volume and the long time required to overcome the inertia of the water in the 20-mile-long pipelines served by the afterbay.

An afterbay control system was provided to automatically control the unit loading by the governor as follows:

1. Regulate power within setpoint limits to maintain the afterbay level within designated elevations.
2. Match, insofar as possible, afterbay flow with turbine flow without regard to power regulation.
3. Allow full governor flyball regulation without regard to afterbay condition.

The control system is the proportional type with manual adjustment of the proportional band width; it varies the unit load based on afterbay water-level changes. A signal generated by a float is introduced into the system whih detects the error between the setpoint and the actual level and feeds the governor speed-adjust transducer with a voltage proportional to error. The transducer then adjusts unit load (flow) through the speed-adjust mechanism until the error is nulled. An analog model of the control system was built to determine system stability and response to varying flow, starting and stopping, and different proportional band widths. Data obtained from this model were used to optimize the design.

A field test was conducted on the control system of Unit No. 1 to verify its behavior under several modes of operation. During the course of the test, some stability problems arose due to afterbay wave action on the float. The problem was temporarily solved by increasing the width of the proportional band. After this adjustment, the system performed satisfactorily in accordance with design criteria. For a permanent solution, an electronic circuit is being provided to cut unwanted signals from the float when the rate of change exceeds the normal expected from the system or when there is a high frequency reversal of float movement characteristic of wave action.

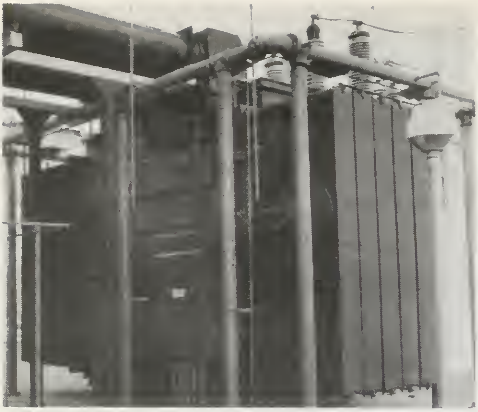

Figure 724. 63.0/84.0-MVA Transformer

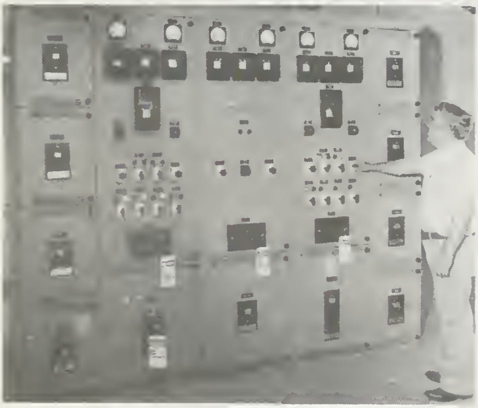

Figure 725. 480-Volt Station Service Switchgear

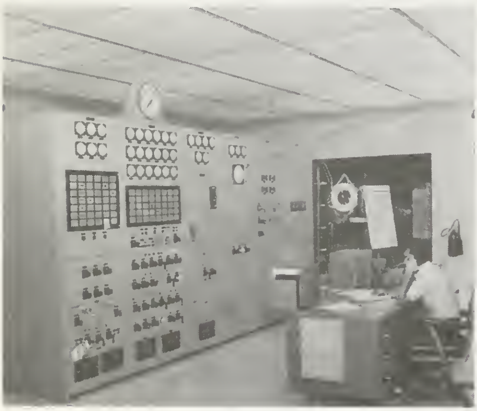

Figure 726. Control Room

Electrical Features

General

The electrical installation includes the generators, switchgear, voltage-regulating equipment, power transformers, switchyard equipment, and the control and auxiliary systems.

General descriptions of electrical systems which are common to other major plants are described in Chapter I of this volume. Items unique to this plant are discussed in following sections.

Description of Equipment and Systems

The 115-kV switchyard contains a single circuit breaker to terminate the transmission line and a single bus to connect the two power transformers through their disconnect switches. Lightning arresters and revenue metering were installed in the switchyard. Power transformers increase the voltage from 13.8 kV.

Two generators are operated and protected by air-blast, station-type, circuit breakers. Capacitors and lightning arresters on the line side of each generator protect from transient overvoltages. Isolated-phase bus connects the low-voltage side of the power transformer to the circuit breakers and generators (Figure 724). The neutral of each generator is connected to ground through the high-voltage winding of a distribution transformer. A resistor is connected to the transformer low-voltage winding. This combination limits ground fault currents and is used to detect abnormal ground currents.

A double-ended substation is used to distribute station service power at 480 volts to various distribution centers located throughout the plant near the loads (Figure 725). Two station service transformers reduce voltage from 13.8 kV and are connected at each end of the substation.

A control room is provided for normal operation of the plant although units can be operated locally at the unit switchboards (Figure 726). Remote control also

Figure 727. Recording Switchboard

is used by the area control center, as described in Volume V of this bulletin. The system will control, monitor, log data, display, and annunciate all necessary points of the plant and switchyard. Protective relays, annunciators, instruments, and meters are mounted on switchboards on a unit basis (Figure 727).

Equipment Ratings

Generators Nos. 1 and 2

Manufacturer: General Electric Company
Type: Vertical-shaft, synchronous
Rated capacity: 63,000 kVA
Speed: 277 rpm
Power factor: 95%
Frequency: 60 Hz
Phase: 3
Volts: 13,800

Power Transformers Nos. 1 and 2

Manufacturers: Federal Pacific Electric Company—No. 1
Westinghouse Electric Corporation—No. 2
Volts: 115-13.2 kV
Taps: In the high-voltage winding, 2½ and 5% above and below 115 kV
Phase: 3
Frequency: 60 Hz
Capacity: 63,000/84,000 kVA
Type: OA/FA
Connections: Grounded Wye—Delta

Station Service Transformers

Number of transformers: 2
Volts: 13,800—480Y/277
Phase: 3
Frequency: 60 Hz
Capacity: 750 kVA
Type: OA

Generators

Rating and capacity of generators were selected to match the turbine ratings as required for head and flow conditions. Electrical and mechanical characteristics are within standard ranges established by manufacturers, resulting in lower cost machines. Generators have direct-connected exciters and static voltage regulators (Figure 728). Regulators are thyristor type using silicon-controlled rectifiers in the output circuit that drives the exciter field. The excitation system has both automatic voltage regulator and manual exciter field rheostat control functions for controlling the generator terminal voltage and also includes various limit, compensator, and start-up circuits.

One lower guide bearing and one upper guide and thrust bearing were required in each generator to give maximum stability, both for short-circuit and earthquake conditions. The relatively high speed of the machines and minimum space requirements for the turbine made it desirable to design the thrust bearing for removal from above the rotor. Adequate headroom could also be obtained with minimum cost.

Generators were furnished under separate contracts as Unit No. 2 was scheduled for operation three years later than Unit No. 1. Since spare parts, tools, and handling equipment would not be needed if the second generator was essentially the same as the first generator, alternative bidding was provided to gain the advantage of this possible reduction in costs. One alternative provided for the manufacturer of the first generator to bid without furnishing the duplicate parts; the second alternative was available to other manufacturers who were required to furnish the completed work. The manufacturer of generator No. 1 was the low bidder in bidding generator No. 2 as a "near duplicate".

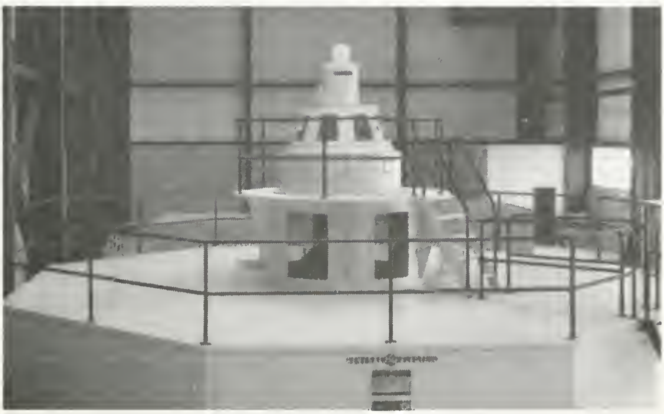

Figure 728. 63-MVA Generator

115-kV Switchyard

The switchyard was designed to serve the Powerplant as initially constructed, without provision for future expansion. One circuit terminates the transmission line and connects to the single bus circuit (Figure 729). Disconnect switches connecting the power transformers to the bus have the capability of interrupting magnetizing current of the transformers. This arrangement allows a transformer to be deenergized while the other unit is under full load. Strain-type rather than rigid-type bus was used for the main run to provide better protection from damage by earthquake. Revenue metering and lightning arrester protection are provided in the switchyard.

Generator Breakers

Interrupting requirements for the short circuit kVA of the 13.8-kV system required the use of air-blast station-type breakers (Figure 730). An alternative to this selection would have been to use breakers in the high-voltage side of each transformer. General space savings favored use of low-voltage breakers. Station service also can be maintained with one of the generators out of service. Economics and convenience of operation were the main factors which influenced the decision to use 13.8-kV breakers. Isolated-phase bus was used to connect between the generator, circuit breaker, and transformer because it has the same system integrity as the station-type circuit breakers.

Figure 730. 15-kV Generator Breaker

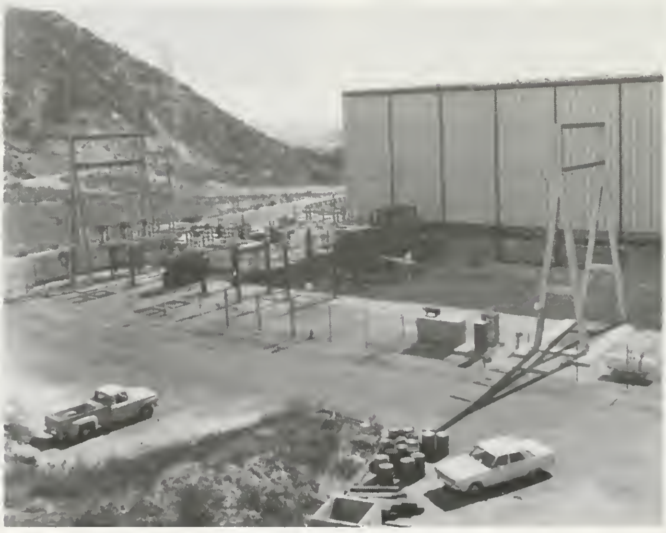

Figure 729. 115-kV Switchyard

Construction

Contract Administration

Table 14 includes general information about the major contracts for the construction of Devil Canyon Powerplant. The principal construction work was performed as part of four large contracts. The furnishing and installing of major equipment was by separate contracts.

Excavation

Excavation for Devil Canyon Powerplant and appurtenances was performed between September 1969 and June 1970. Four areas were excavated: (1) the flood channel; (2) the afterbay; (3) the west ridge, which forms the west slopes of the afterbay; and (4) the plant site, which included a portion of the penstock adjacent to the plant.

Material excavated from the flood channel and the afterbay was extremely rocky (Figure 731). Large bulldozers and a front-end loader were employed to excavate and load this material into trucks, which hauled the material to designated Waste Area No. 3. Some of the boulders encountered in this excavation were so large that it was necessary to split them with a hydraulic rock splitter before further handling.

Most of the excavation occurred at the plant site and west ridge area. Self-loading scrapers began these excavations from the west ridge, loading downhill and carrying their loads to mandatory Spoil Levees Nos. 5 and 7. Early in October 1969, it was determined that much of this material would be required for the construction of the roads located south and west of the afterbay. In order to use this material for the road fills, removal of material greater than 5 inches in size was required.

Excavated material was pushed from the slopes by bulldozers onto a grizzly installed over a belt loader which fed the scrapers. This material was placed in the road embankments or hauled to mandatory Spoil Levees Nos. 5 and 7. Oversized material was hauled to Waste Area No. 3. Spoil Levee No. 6 was not constructed because of shortage of material.

The flood channel was overexcavated approximately 15 inches and backfilled with the minus 5-inch material obtained from the west ridge excavation so that the subdrainage system could be installed in the finer backfill material. After installing the subdrainage system, the backfilling of the flood channel was completed using material from the belt loader. Compaction was obtained with a vibratory roller and by wheel rolling.

Material for the clay membrane located at the flood channel inlet was obtained from a clay borrow area approximately 1 mile north of the powerplant site adjacent to the penstock trench. Clearing and explora-

TABLE 14. **Major Contracts—Devil Canyon Powerplant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Turbine, governor, and valve	68-41	$1,778,749	$1,872,264	$40,000	2/17/69	11/30/73	Baldwin-Lima-Hamilton
generator	68-59	978,015	1,178,757	28,509	4/14/69	1/15/74	General Electric Co.
Devil Canyon Powerplant	69-10	7,528,799	9,246,228	1,263,216	9/ 2/69	1/ 7/72	Vinnell Corp.
Power transformer	69-22	162,603	171,819	1,000	10/24/69	3/30/73	Federal Pacific Electric Co.
Generator switchgear and station service transformer	69-26	146,018	165,000 (Est.)	—105*	11/26/69	12/74 (Est.)	General Electric Co.
Penstock	70-02	4,973,446	5,733,817	381,176	4/ 2/70	8/23/72	Zurn Engineers
Station service switchgear	70-03	61,280	64,483	—78	4/10/70	2/ 4/74	Westinghouse Electric Corp.
Main control and recording switchboards	70-09	114,075	128,000 (Est.)	6,394*	5/26/70	12/74 (Est.)	Golden Gate Switchboard
Completion of Devil Canyon Powerplant	70-18	1,890,277	2,523,814	153,859	8/27/70	1/31/73	Wismer & Becker Contracting Engineers
Strong-motion acceleration monitoring systems (including Pearblossom Pumping Plant and Devil Canyon powerplant	71-13	86,028	94,219	--	6/ 9/71	12/ 4/72	Electra-Physics
Turbine, governor, and valve—Unit II	72-05	1,904,860	1,925,000 (Est.)	--*	7/26/72	9/75 (Est.)	Sulzer Bros. Inc.
Generator—Unit II	72-22	1,273,000	1,280,000 (Est.)	--*	3/ 2/73	1/76 (Est.)	General Electric Co.
Stoplogs and lifting beam—Devil Canyon Powerplant	73-03	62,300	68,818	6,517	4/ 2/73	11/16/73	Altius Corp.
Power transformer—Unit II	73-26	197,443	217,000 (Est.)	--*	8/23/73	8/75 (Est.)	Westinghouse Electric Corp.

* As of November 1974


Figure 731. Excavation in the Flood Channel


Figure 732. Afterbay Riprap


Figure 733. Placing Riprap at Inlet to Flood Channel

tion of the borrow area began in October 1969. Bulldozers cleared the area and pushed the clay material into stockpiles which were tested for specification compliance. The approved material was loaded into dump trucks and hauled to the flood channel inlet, where it was stockpiled for later use.

Excavation for the clay membrane in the flood channel consisted of a trench with approximately ¾:1 slopes. A large dozer with ripper pushed the material into piles, and a loader hauled it out of the trench where it was loaded into dump trucks, or stockpiled. A 2-foot-deep key for the membrane was excavated into the rock foundation with a tractor-mounted ripper and a jackhammer. The excavation was wet and required continuous pumping.

Clay membrane for the flood channel inlet was placed in December 1969. The clay was watered in the stockpile and again as it was spread. Roots and oversize material were removed by hand during spreading and compacting. Compacted embankment using minus 5-inch material was constructed on the upstream side of the clay. A combination of wheel rolling with a loader and then a compactor was found to be satisfactory in obtaining the required density.

Material for the clay membrane along the east side of the afterbay was obtained by the contractor from a private site. Excavation for the membrane was started in May 1970. The borrow site was developed by a subcontractor who also hauled the material to the afterbay. The material was placed by a front-end loader and compacted by a bulldozer.

Riprap, most of which was obtained from Waste Area No. 3, was placed on the entire afterbay bottom and side slopes and at the inlet and outlet of the flood channel (Figures 732 and 733).

Concrete Placement

The contractor used a stationary concrete batching and mixing plant. Batches were automatically controlled with a punch-card system having a separate punch card for each mix design.

A tilting-drum mixer dumped concrete into 4-cubic-yard buckets which were placed on haul trucks or a specially designed low-bed trailer powered by a two-wheel tractor. These units conveyed concrete to the placing sites where it was unloaded and hoisted to the forms by a crane. The cranes had an automatic hook, and the bucket gates were hydraulically controlled.

Pneumatic vibrators of 3½-inch diameter were used to consolidate the 1½-inch maximum size aggregate in the flood channel walls. Six-inch vibrators were used for the 3-inch aggregate in the flood channel floor (Figure 734).

Floor slabs were cured by soaker hose and water-saturated burlap and walls by spray from perforated plastic pipe hung along the top.

Concrete was placed as near as possible to 50 degrees Fahrenheit, which necessitated using up to 100% ice instead of water for mixing (Figure 735).

Protective Coatings

Coal-tar epoxy was used as a protective coating for the interior of all steel piping, flow tubes, Venturi meters, and valves. The protective coating for all exposed steel piping, flow tubes, Venturi meters, and valves was inorganic zinc silicate with a tie-coat and a vinyl color coat. A cement mortar or coal-tar epoxy was used on partially buried steel piping, and coal-tar enamel was used on the buried steel piping.

Penstock

The penstock was constructed in steep terrain (Figure 736). Some of the higher ridges required deep cuts. Reinforced-concrete piers were used to span some of the canyons (Figure 737).

Progress was slow during construction of the last 300 feet from the Powerplant due to alignment troubles, out-of-roundness of the pipe, and misalignment of the wye section at the powerhouse, all of which required correction. In addition, when the penstock was erected on sliding supports, elongated holes were found necessary to prevent the pipe from buckling due to expansion under warmer than average weather.

Excavation for the penstock was made with pairs of multiengine motor scrapers hooked together. This system was used to eliminate the need for push tractors to load the units. Instead they loaded each other. After both were loaded, the hookup was disengaged so each unit could travel separately to the dumping area. A large tractor, with slopeboards mounted on each side, was used to finish the cut slopes.

Figure 734. Placing Concrete in Flood Channel Floor Slab

Figure 735. Powerplant Concrete Construction

Figure 736. Penstock Pipeline Being Constructed

Figure 737. Pipe Pedestals and Piers

As the grading progressed, excavation for pipe pedestals began. Each pad acted as a base for two pairs of pedestals. Each pair supported a ring girder installed at both ends of each pipe section during fabrication. Compaction of the pad subgrade was performed with hand-operated machine vibrators because of the limited work space. At the summit of each hill and the bottom of each canyon where the penstock had a vertical curve, concrete encasement of the penstock was necessary for an anchor block (Figure 738). Excavation for the anchors was performed with a backhoe.

Concrete was transported to the work sites in transit mix trucks. In many areas where access was difficult, concrete was either pumped or conveyed by belt. In more easily accessible areas, concrete was chuted directly into the forms or hoisted by crane in concrete buckets.

Where the penstock alignment crossed a canyon, concrete piers were constructed. In other canyons, the pipe was encased in reinforced concrete below streambed. The penstock also passes under the San Bernardino Tunnel access road at two locations.

Other Construction

Construction of the powerplant superstructure and other building components was routine.

The first turbine unit was manufactured and installed by Baldwin-Lima-Hamilton under separate contract and the generator by the General Electric Co., also by separate contract. The installation was routine.

The turbine, governor, and valve for Unit No. 2 is being furnished and installed by Sulzer Bros. under separate contract, Specification No. 72-05. Unit No. 2 generator is being furnished and installed by the General Electric Company, also under separate contract, Specification No. 72-22.

Figure 738. Reinforced-Concrete Pipeline Encasement

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 739 through 756).

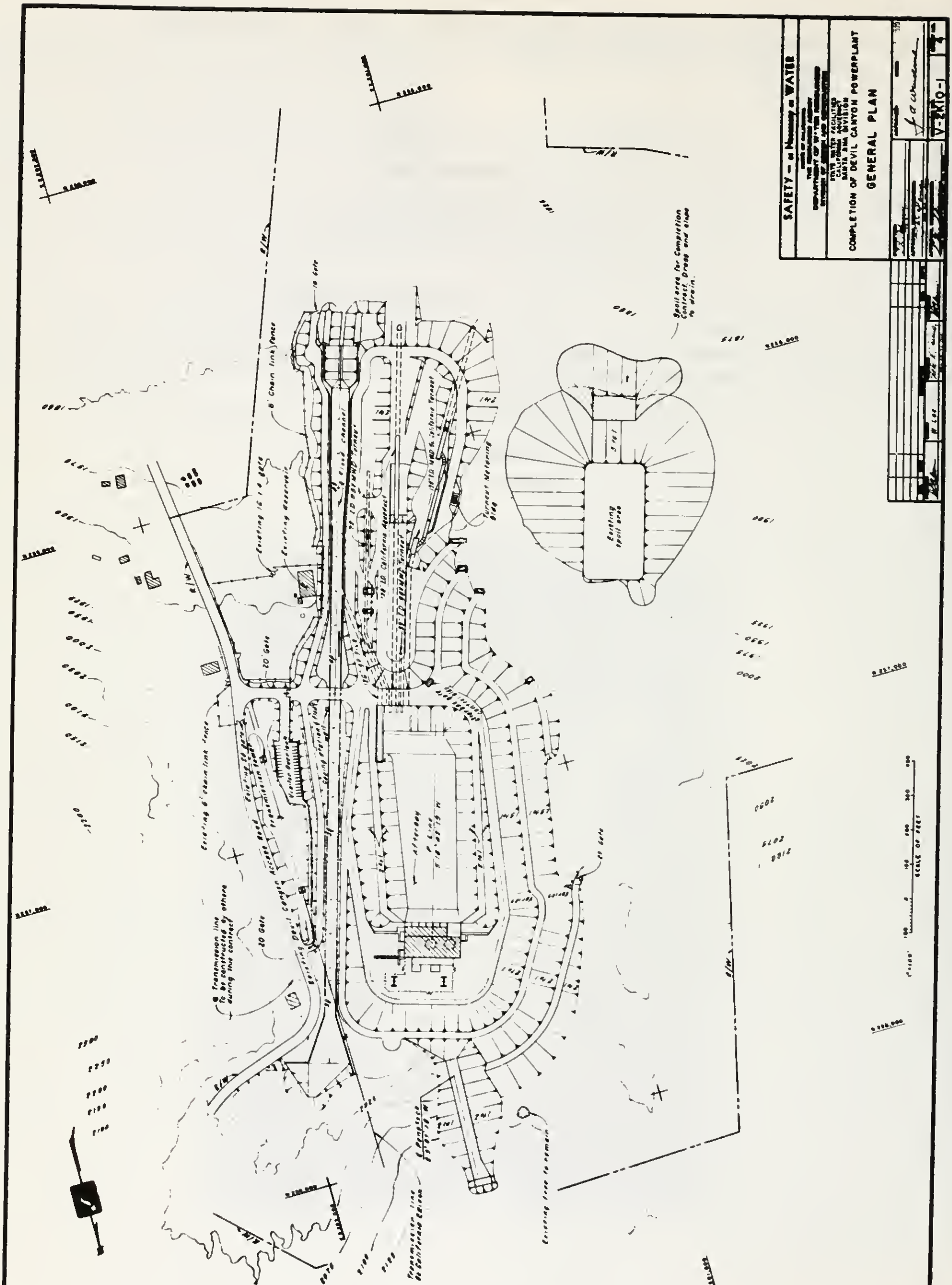

Figure 739. General Plan

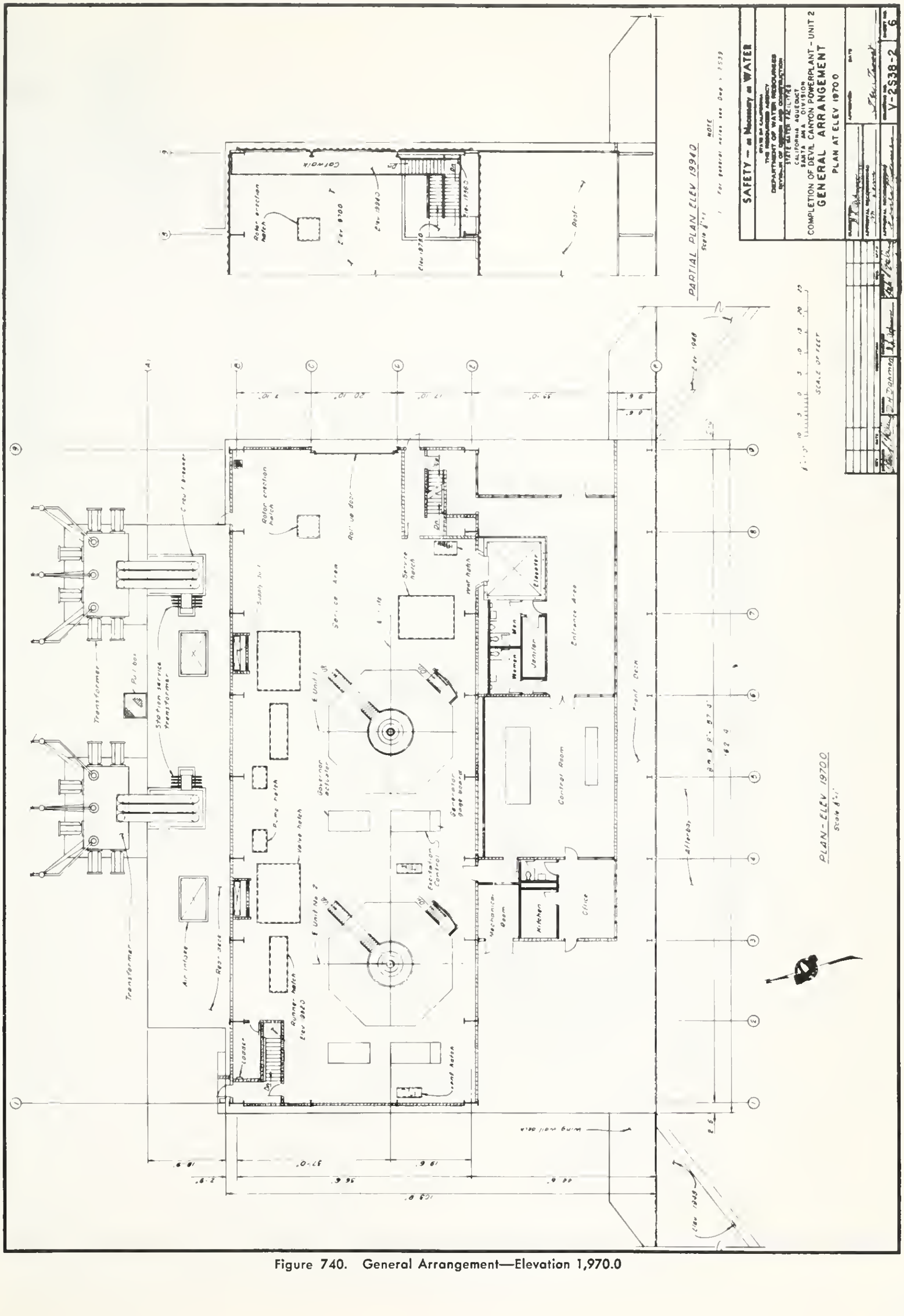

Figure 740. General Arrangement—Elevation 1,970.0

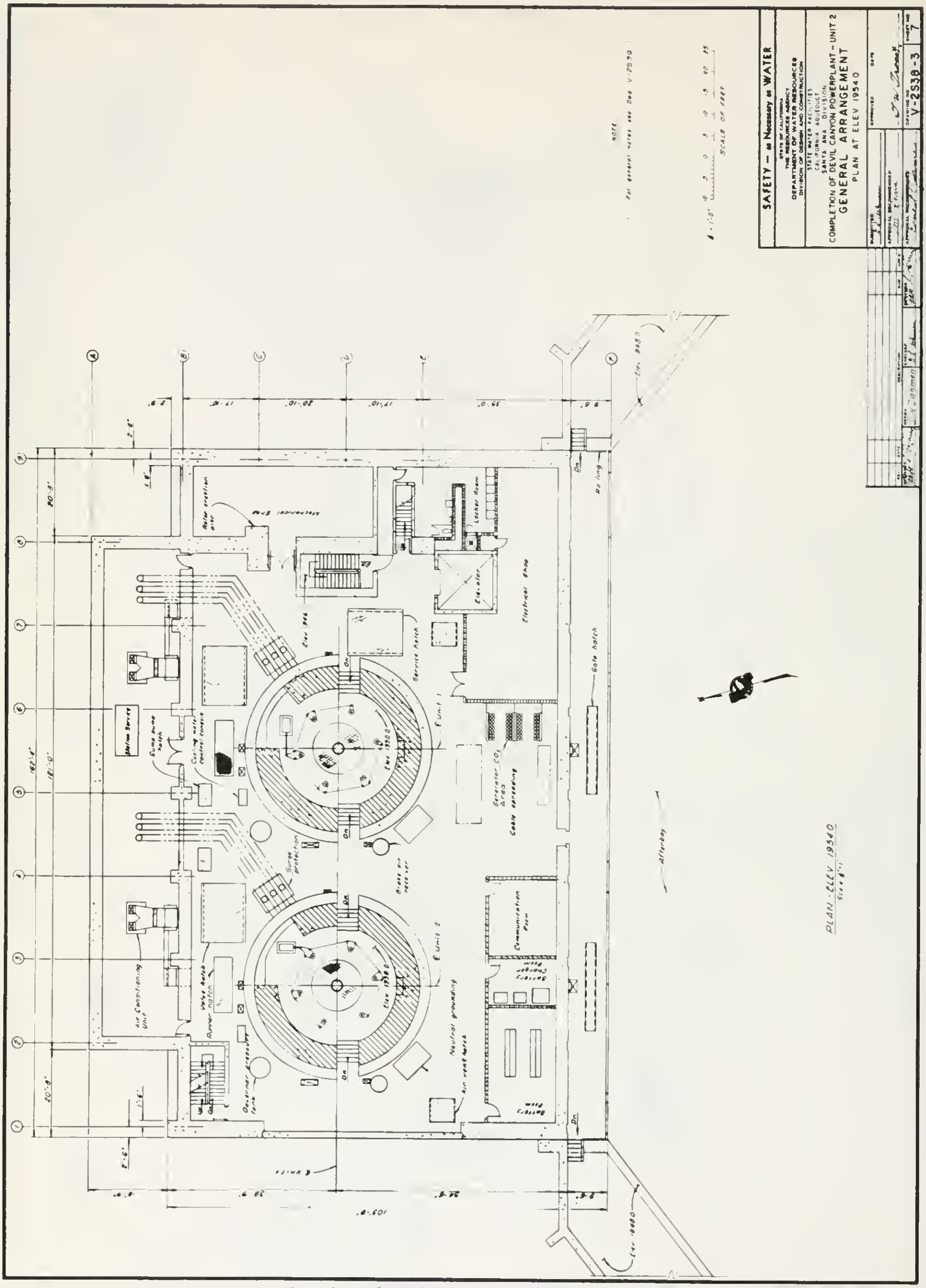

Figure 741. General Arrangement—Elevation 1,954.0

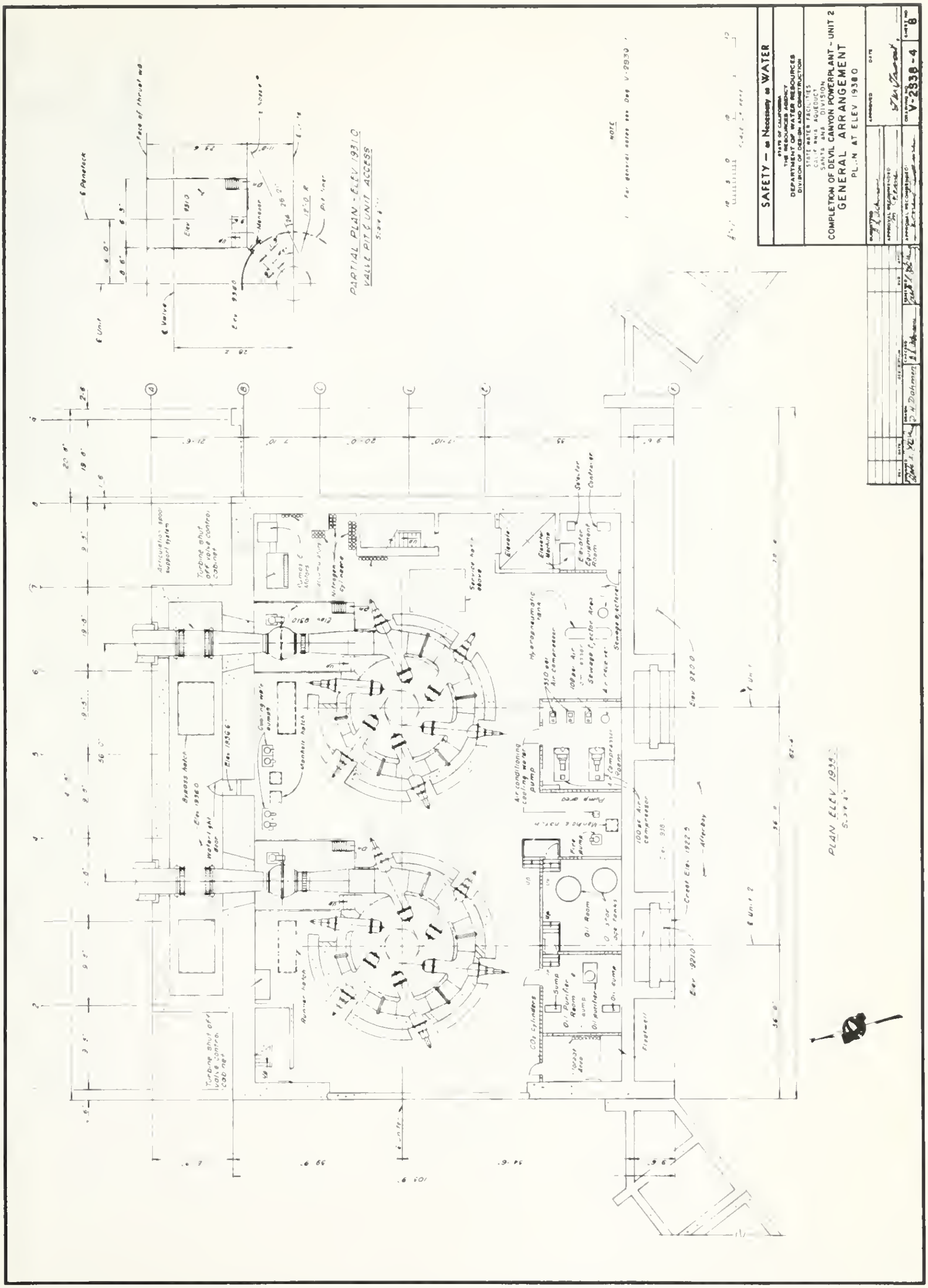

Figure 742. General Arrangement—Elevation 1,938.0

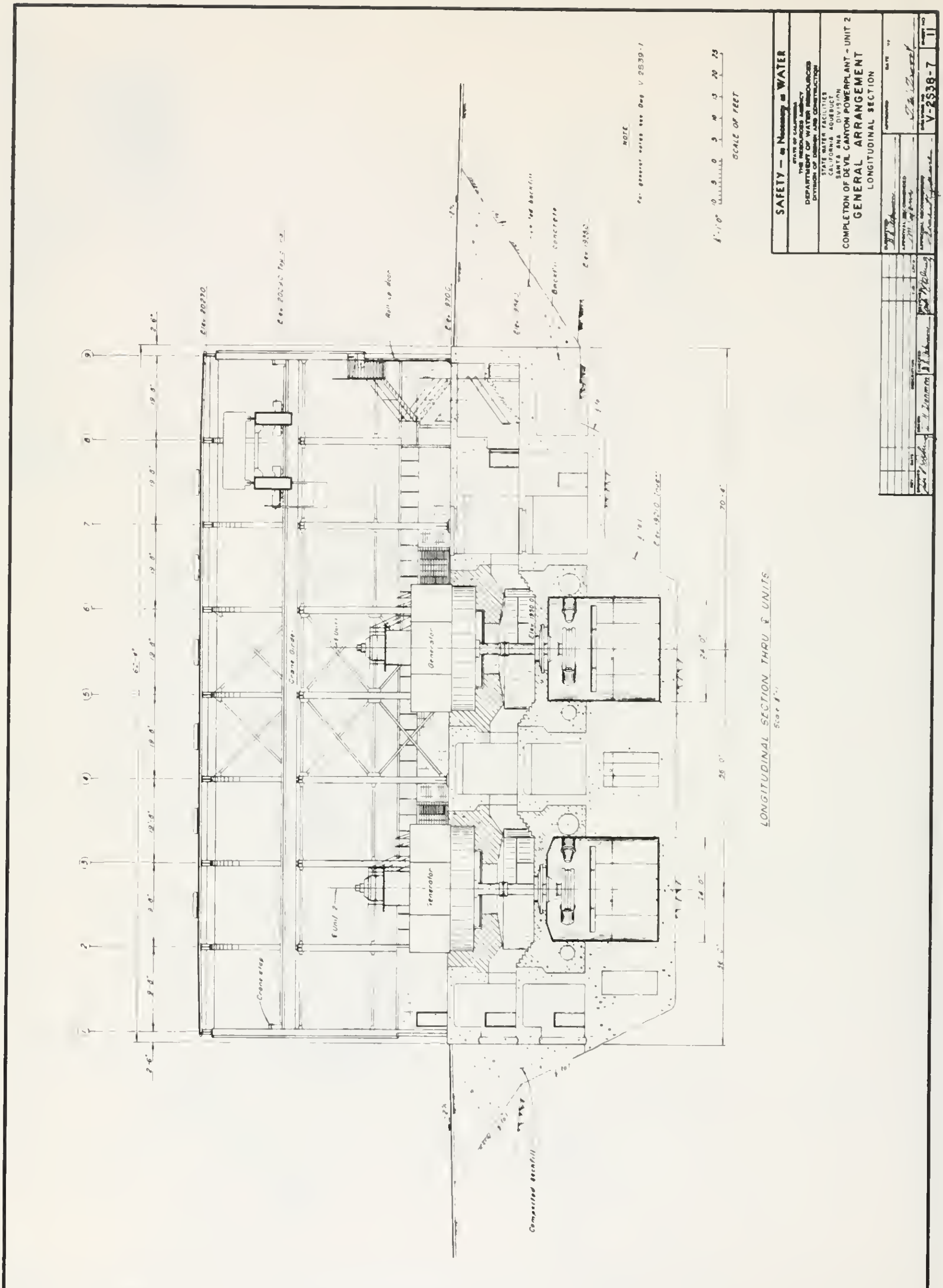

Figure 743. General Arrangement—Longitudinal Section

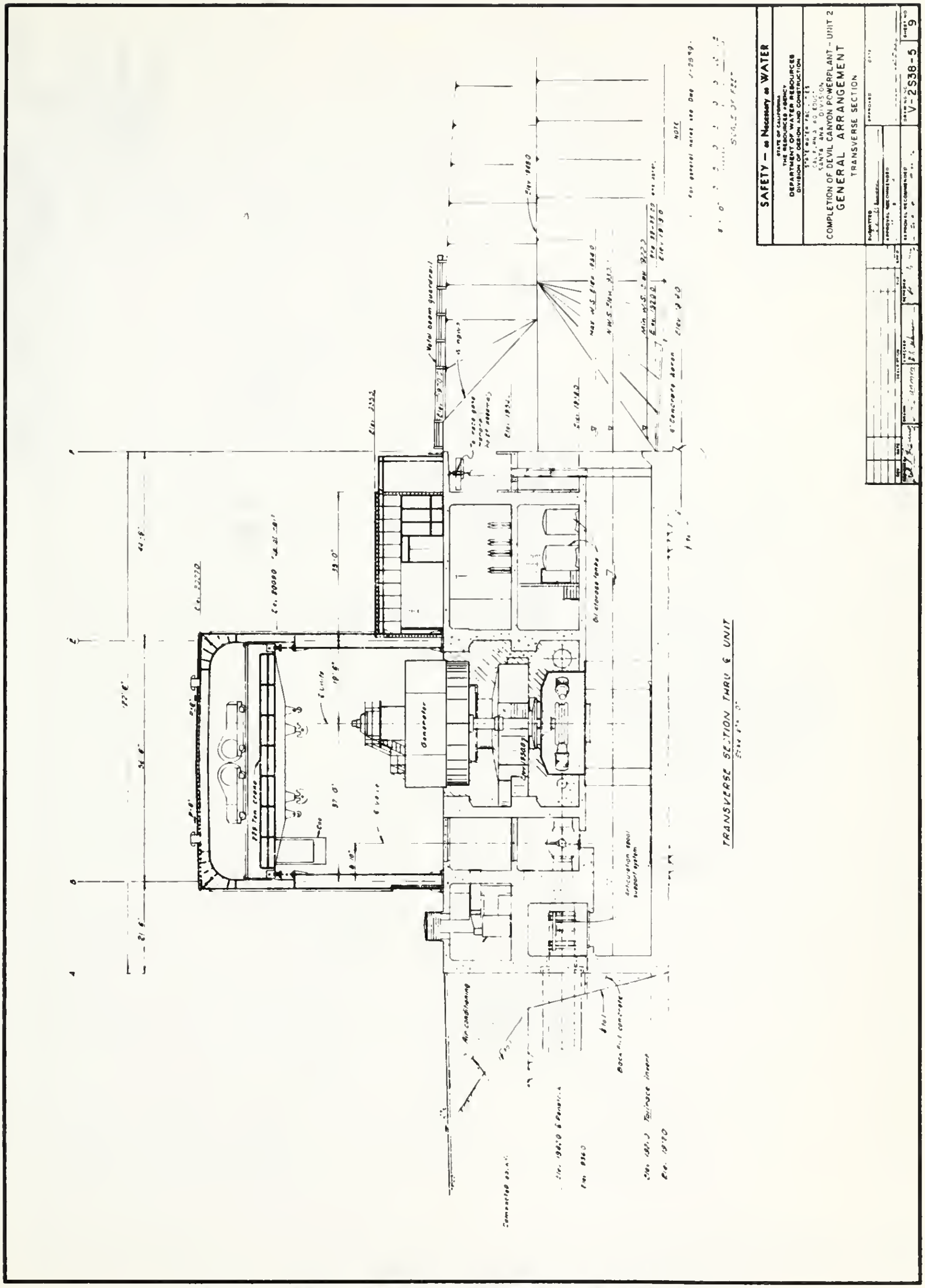

Figure 744. General Arrangement—Transverse Section Through Centerline of Unit

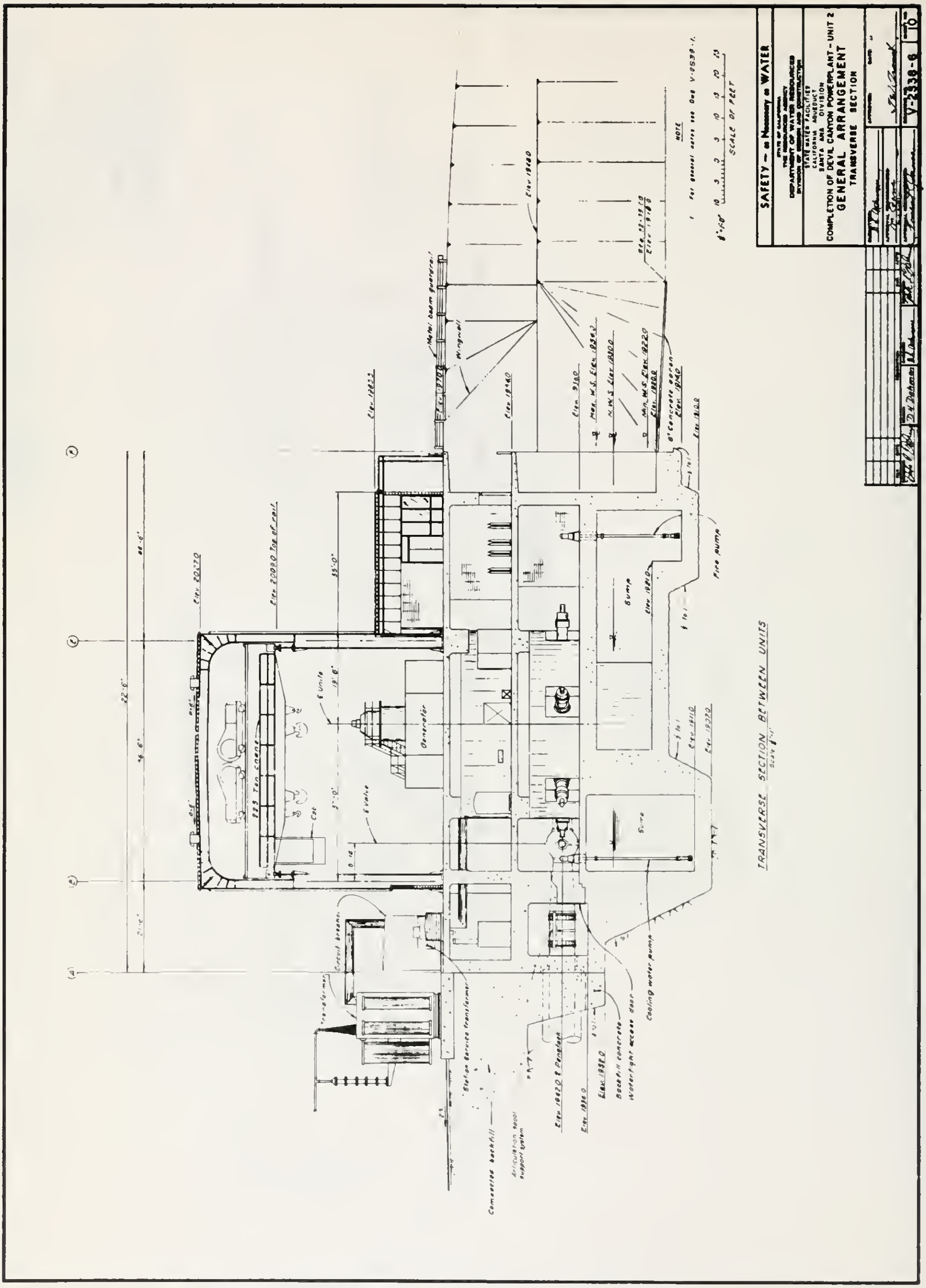

Figure 745. General Arrangement—Transverse Section Between Units

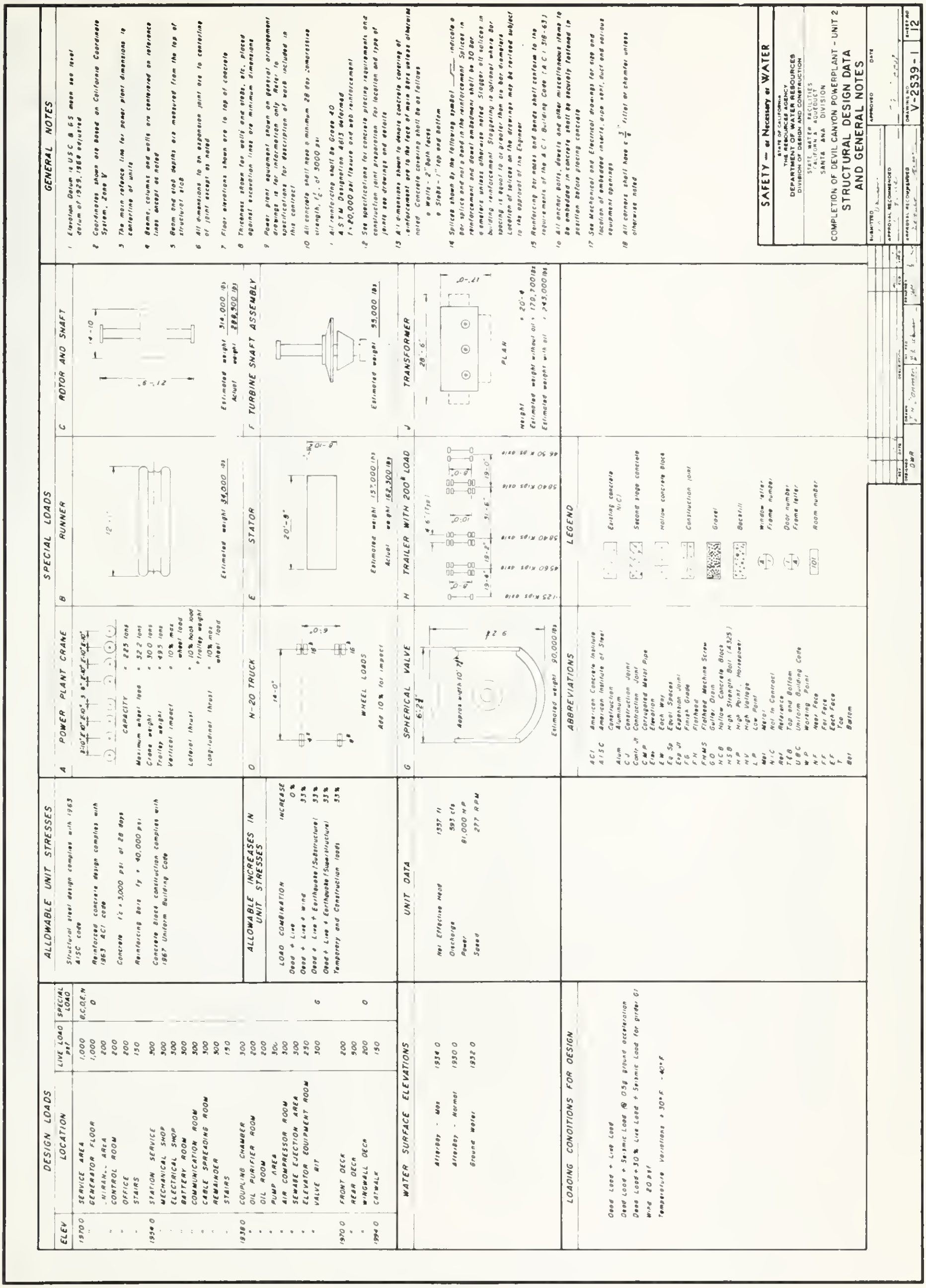

Figure 746. Design Data

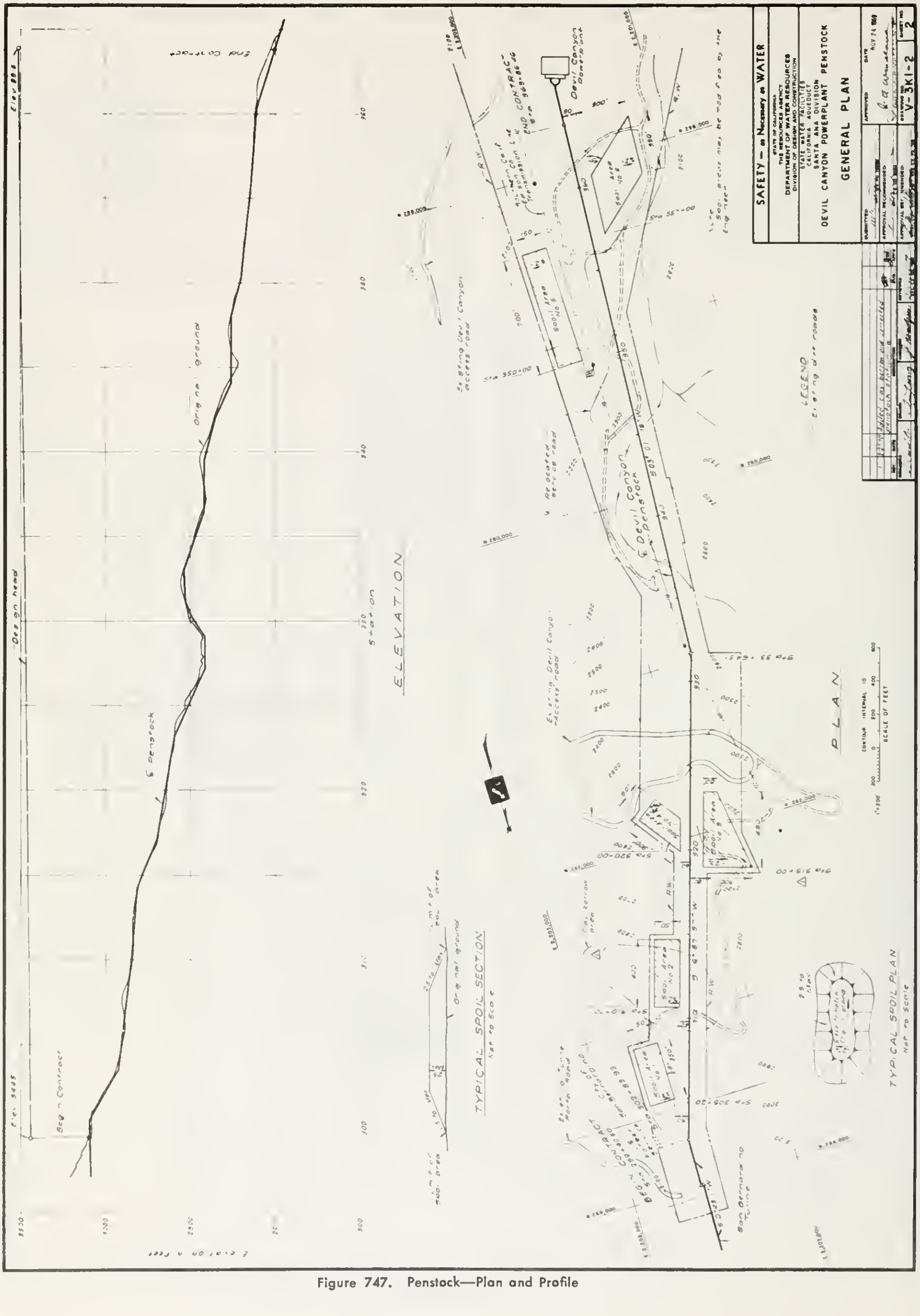

Figure 747. Penstock—Plan and Profile

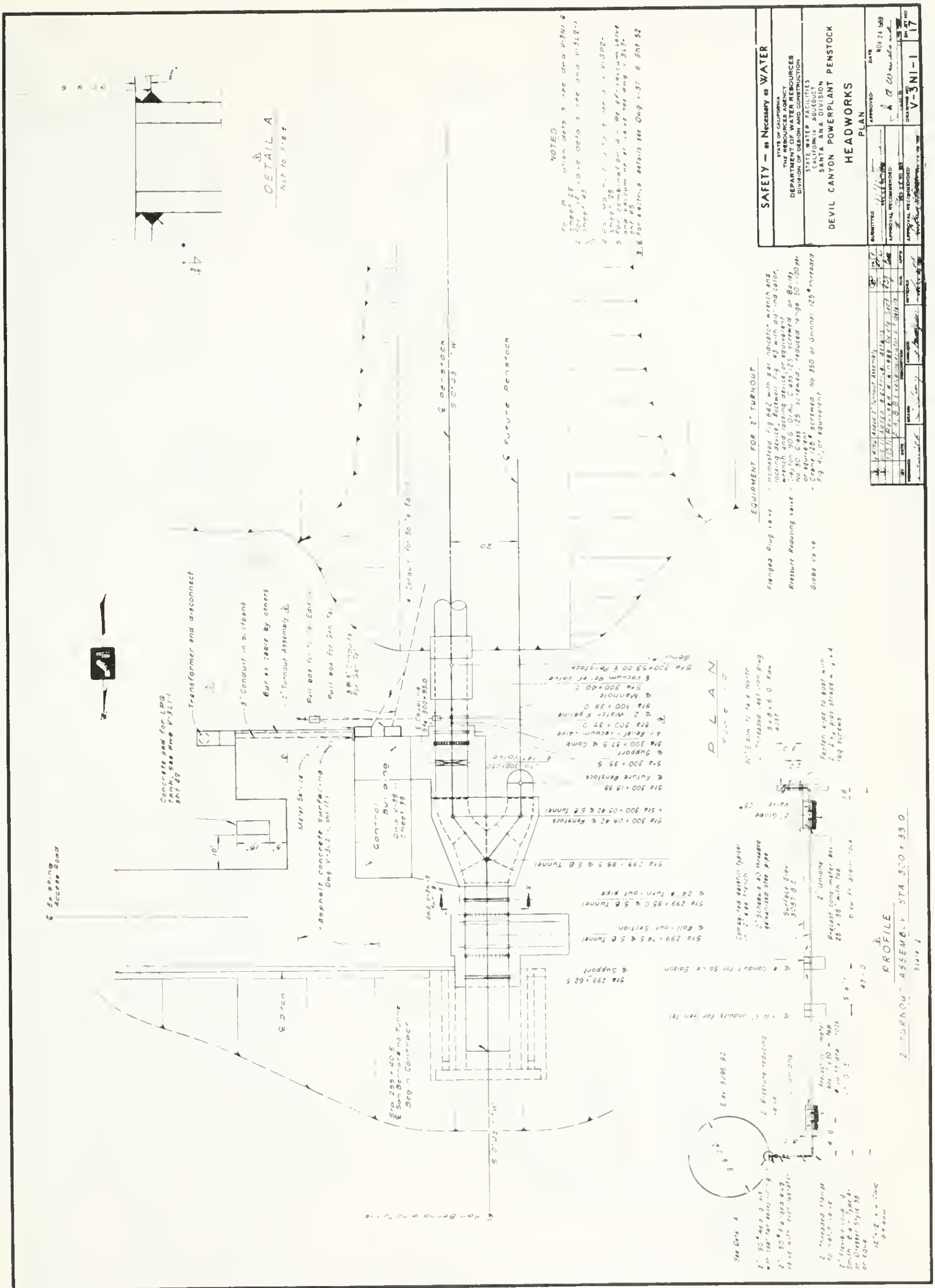

Figure 748. Headworks—Plan

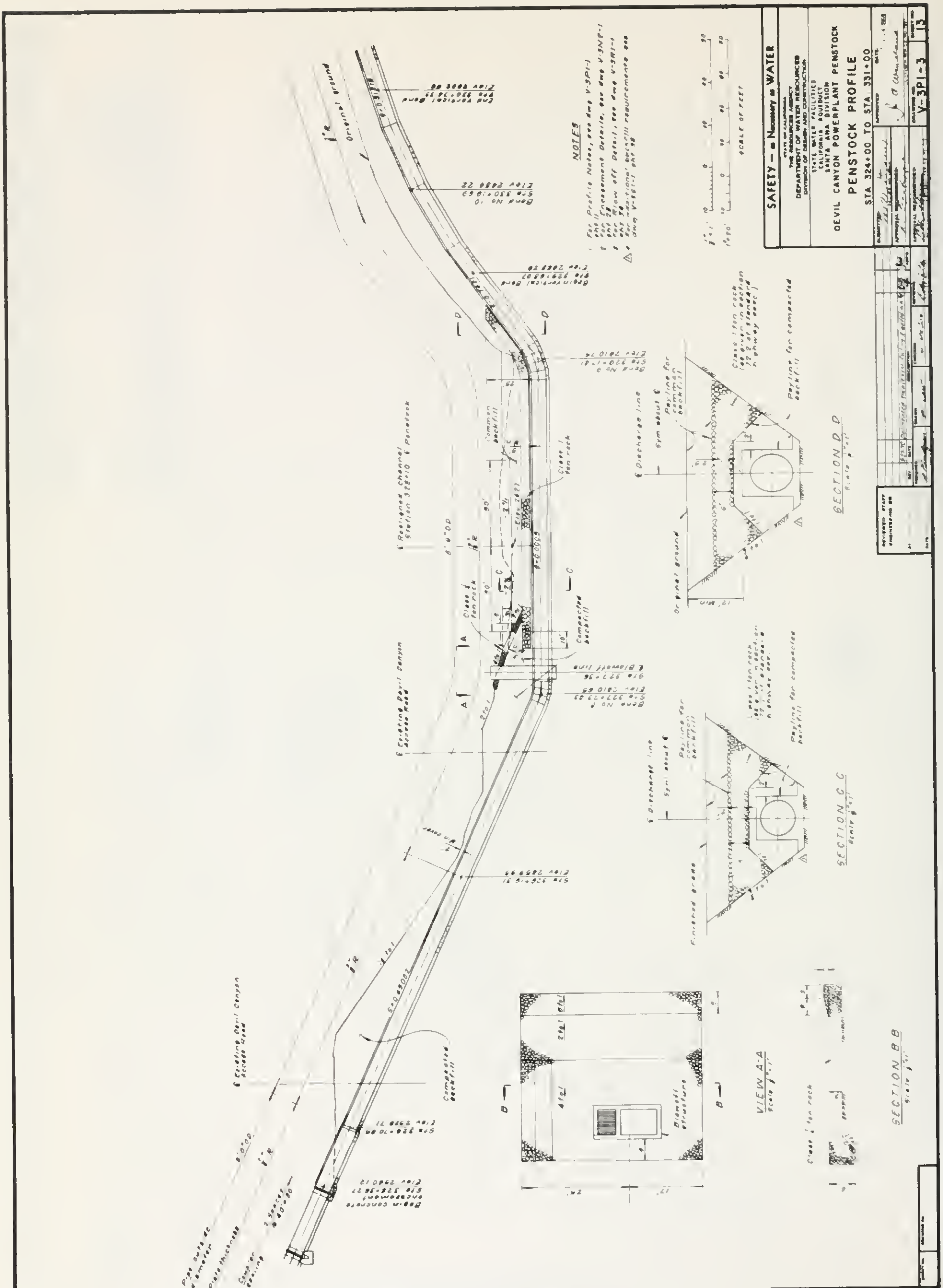

Figure 749. Devil Canyon Creek Crossing

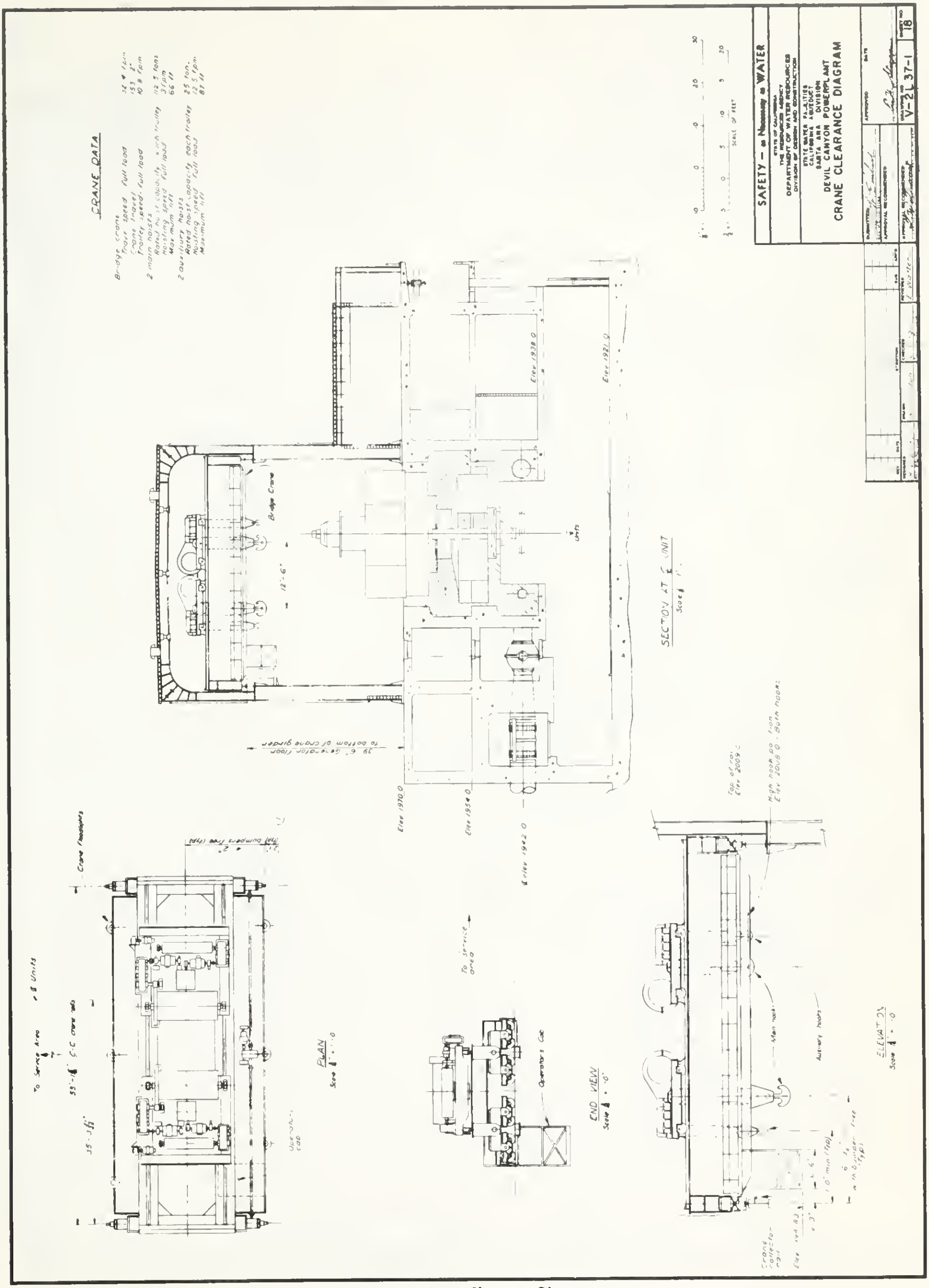

Figure 750. Crane Clearance Diagram

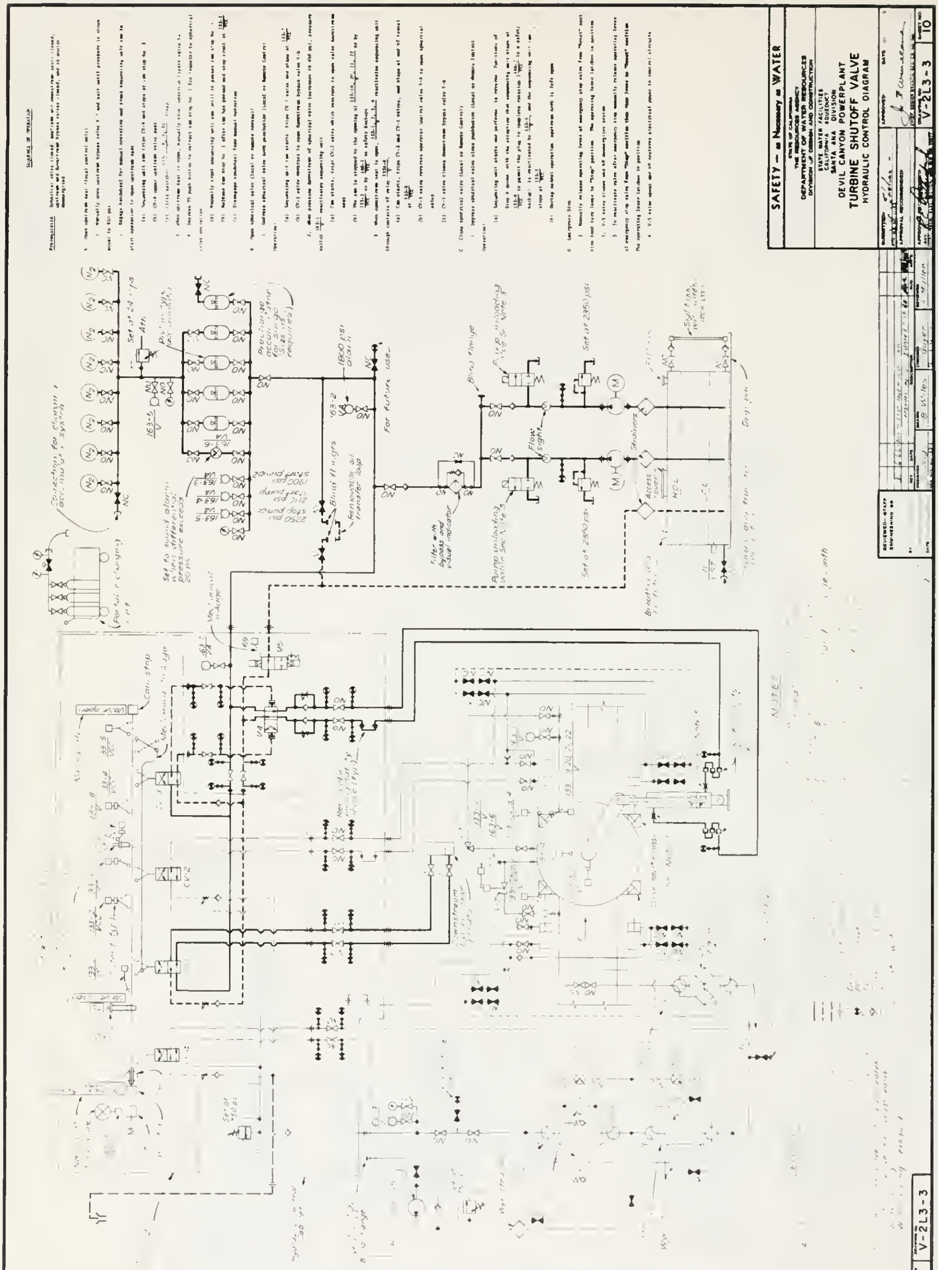

Figure 751. Spherical Valve Hydraulic Schematic

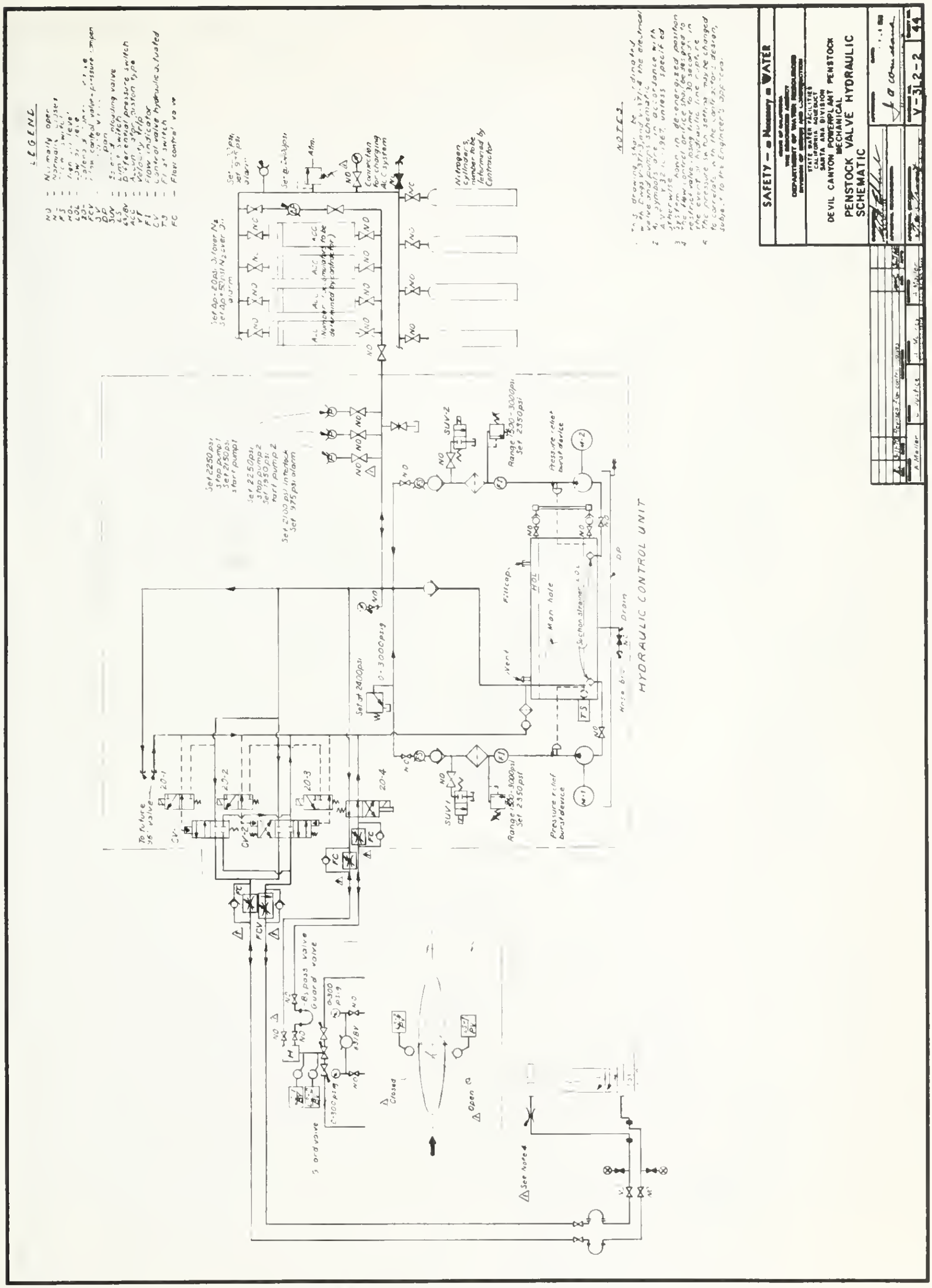

Figure 752. Penstock Valve Hydraulic Schematic

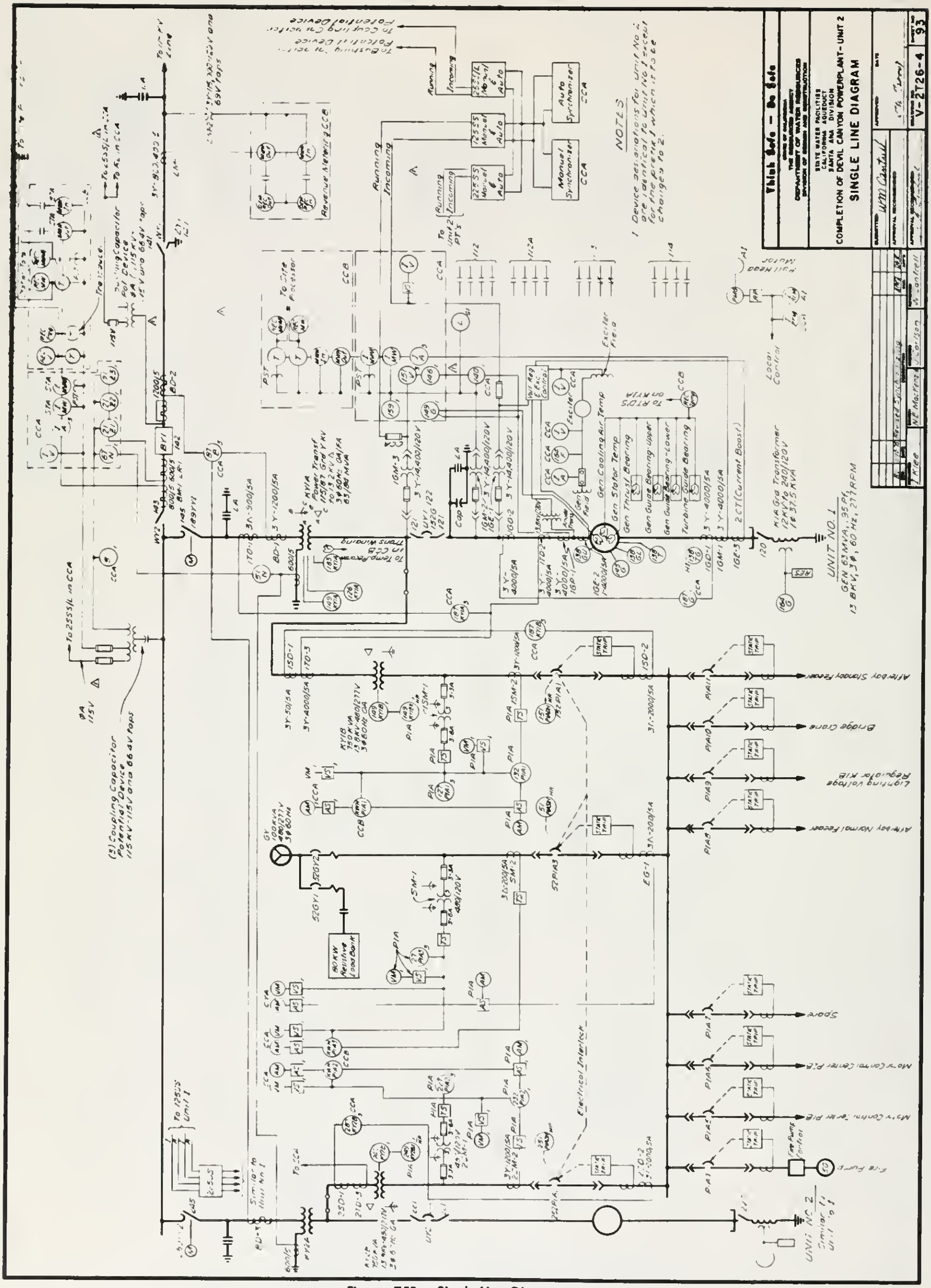

Figure 753. Single-Line Diagram

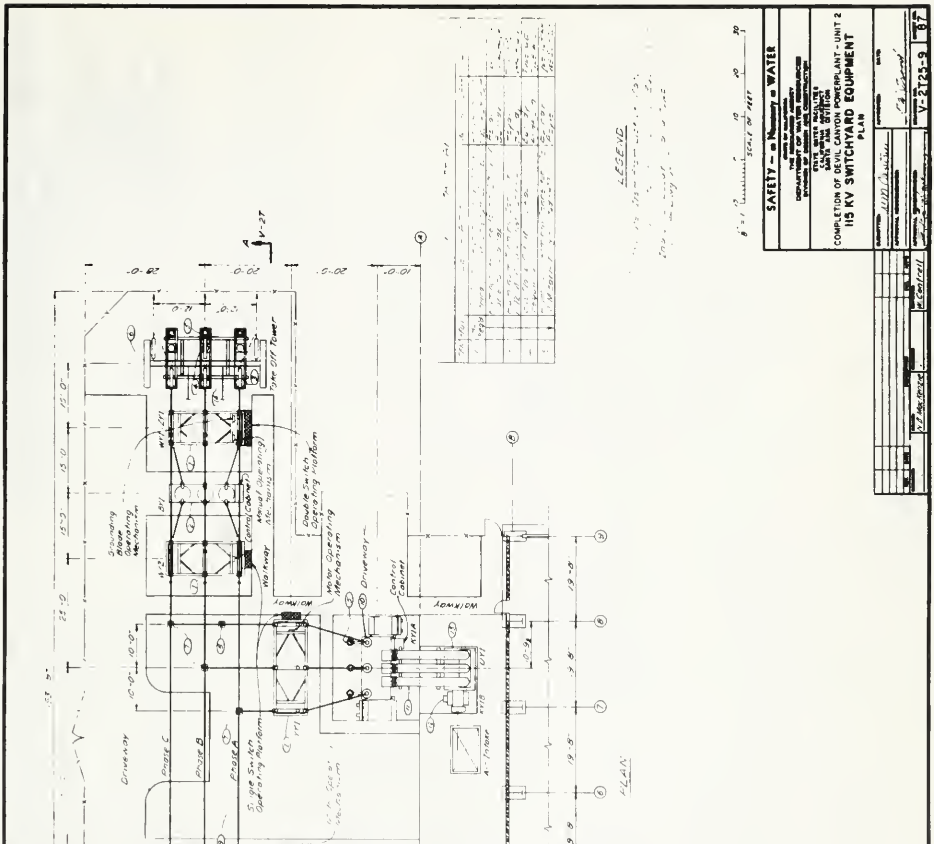

Figure 754. 115-kV Switchyard Equipment—Plan

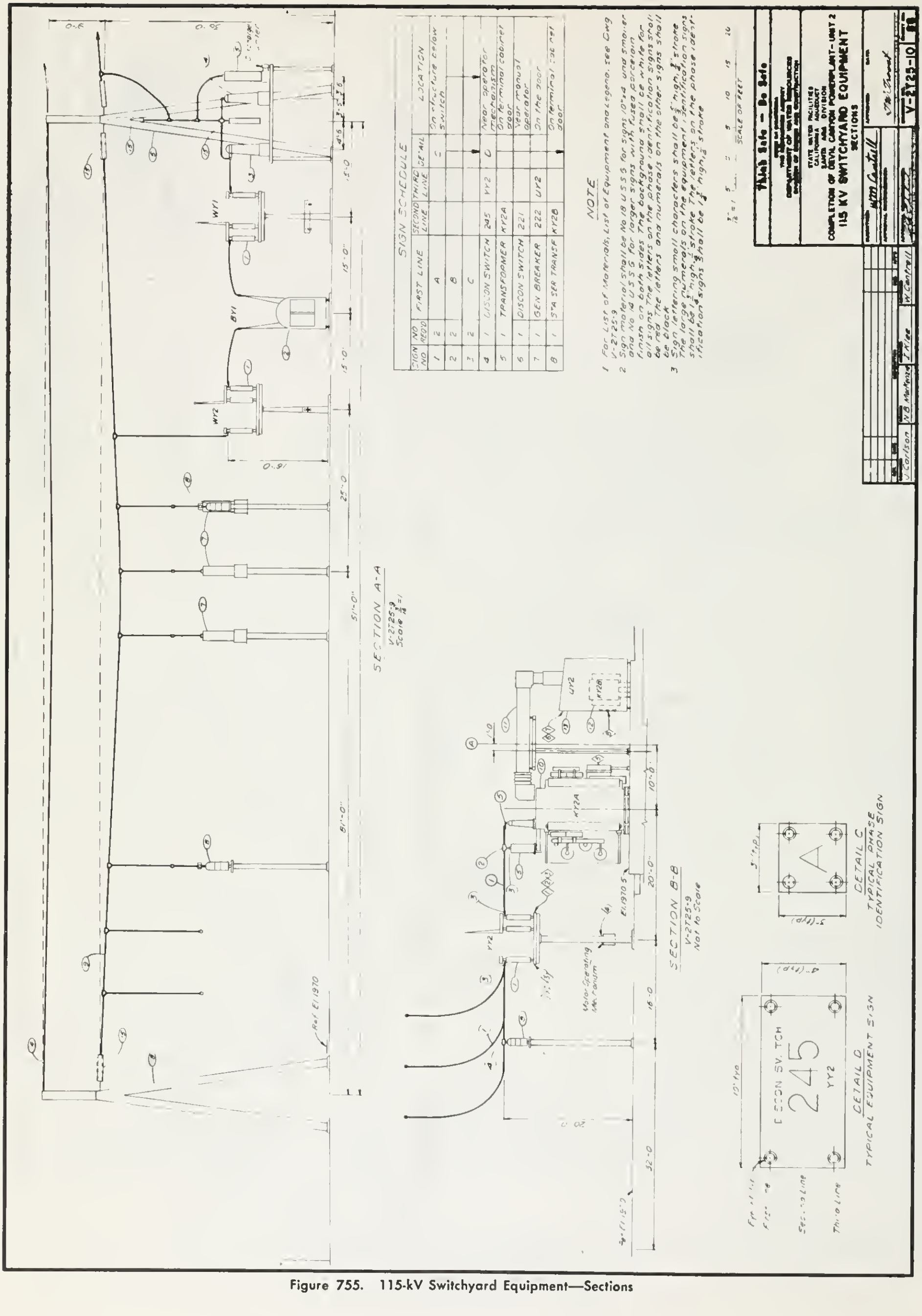

Figure 755. 115-kV Switchyard Equipment—Sections

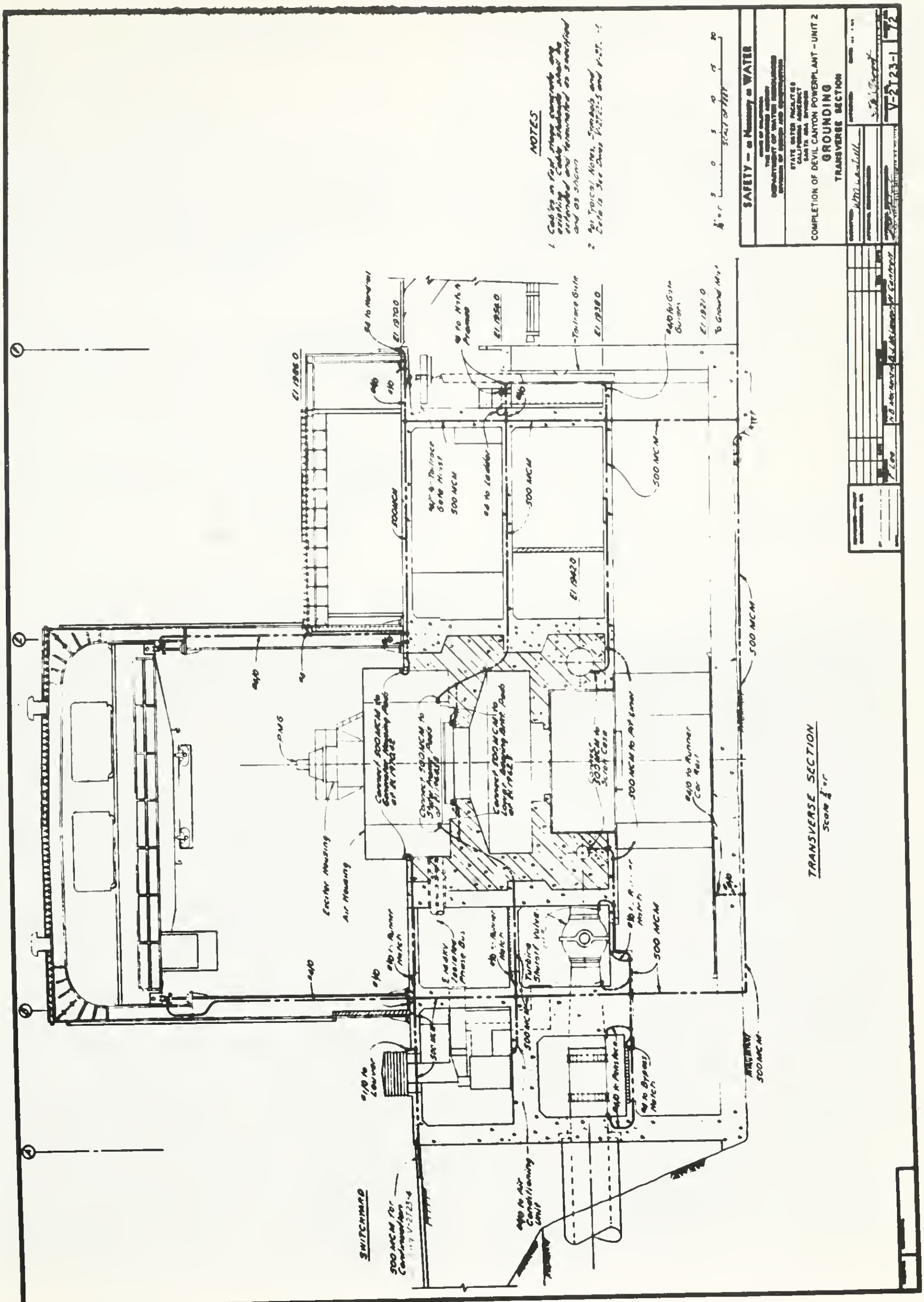

Figure 756. Grounding

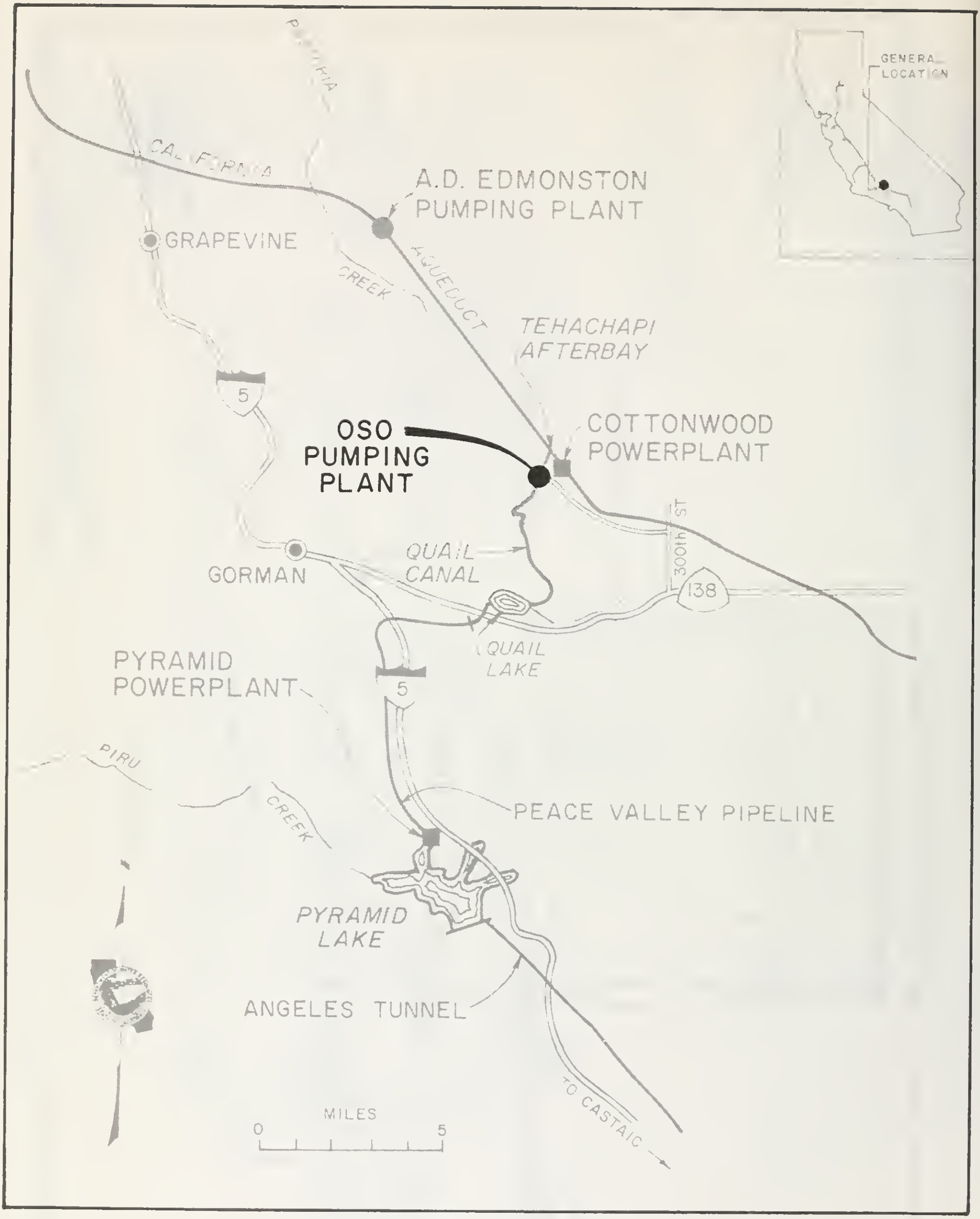

Figure 757. Location Map—Oso Pumping Plant

CHAPTER XVI. OSO PUMPING PLANT

General

Location

Oso Pumping Plant is located on the Los Angeles-Kern County line approximately 7 miles east of Gorman and 40 miles west-northwest of Lancaster. The nearest major roads are State Highway 138 and Interstate Highway 5 (Figures 757 and 758).

Purpose

This plant, the first major structure on the West Branch of the California Aqueduct, lifts water 231 feet from Oso Canal to Quail Canal. Quail Canal extends from Oso Pumping Plant into Quail Lake.

Description

The Oso Pumping Plant facilities consist of a canal intake transition, indoor-type plant with eight pumping units, switchyard, five discharge pipelines, and siphon outlet.

The eight pumping units provide the plant with a total capacity of 3,128 cubic feet per second (cfs). Each pumping unit consists of a vertical-shaft, single-stage, centrifugal pump and a vertical-shaft, synchronous, electric motor. There are four large pumping units and four small pumping units.

Each large unit has a capacity of 625 cfs and discharges through a 78-inch butterfly valve into a 108-inch pipeline. Each small unit has a capacity of 157 cfs and discharges through a 36-inch spherical valve. The discharges of the small units are combined by a wye manifold into a single 108-inch pipeline.

The discharge pipelines are each approximately 2,020 feet long and extend through a siphon to the outlet at the head of Quail Canal.

Representative drawings are included at the end of this chapter.

Geology

Areal Geology

Oso Pumping Plant is in a wide, flat, alluvial plain at the western end of Antelope Valley in the triangular wedge formed by the Garlock and San Andreas

Figure 758. Aerial View—Oso Pumping Plant

faults. The site is bordered on each side by low flat-lying hills composed of terrace deposits. The Tehachapi Mountains are to the north; Bald and Liebre Mountains, along the San Andreas rift zone, are to the south. Terrace deposits extend beneath the alluvium, and both are underlain by Pliocene lake deposits.

Site Geology

Alluvium is the foundation material for the approach channel and the greater portion of the Pumping Plant. These deposits consist of a 30-foot zone of loose, nearly horizontal, gray to tan sediments of silt, sand, and gravel and a lower zone of denser, brown to orange, sand and gravel.

Terrace deposits were exposed throughout the length of discharge line excavation and are exposed in the southeast and southwest corners of the pumping plant bowl. Terrace deposits consist of red to reddish-brown silty sand and poorly graded sand with numerous lenses of poorly graded gravel, fine sand, and silt. The general dip is northerly at 1 to 3 degrees, except along the south side of the bowl where folding along an east-west axis has reversed the dip. Cross-bedding is common within individual lenses.

Pliocene lake deposits were exposed in the drainage dewatering sump area, the deepest part of the foundation. These deposits are nearly horizontal, thinly bedded, green, red, and brown claystones. The claystones are soft, weak, plastic rocks with numerous internal slickensides and shears.

With the exception of a small area of lakebed deposits under the drainage dewatering sump, all material encountered in the excavation was suitable for foundations. The lakebed area was overexcavated and backfilled with gravel to sustain the moderate load in this section of the plant.

A dewatering system was required in the pumping plant area, and wells with submersible pumps were installed. The maximum quantity of water pumped from the plant foundation was about 500 gallons per minute (gpm).

Geologic Exploration

Exploration consisted of 13 diamond drill holes, 17 bucket auger holes, a seismic survey, and a pump test. Penetrometer readings were taken during drilling. Shelby tube and bag samples were taken for testing. Pump tests were conducted to obtain permeability data for dewatering requirements.

Instrumentation

Instrumentation at the Oso Pumping Plant site during construction included four buried-type and three cased-type rebound gauges, and two slope-indicator casings.

A strong-motion seismograph and a tiltmeter are located on the west rim of the bowl excavation. During site excavation, rebound was recorded on all three cased gauges. A maximum upward movement of 0.69 of a foot was recorded. No movement was detected in the slope-indicator holes.

The tiltmeter recorded almost no tilting before excavation. During excavation, the tiltmeter responded to rebound of the alluvium.

Seismicity

The Garlock fault is 6 miles to the northwest, and the San Andreas rift is 3 miles to the southwest. The area is seismically active, and it is possible that a major earthquake will occur within the life of the plant. The San Fernando earthquake of February 9, 1971 was recorded on the strong-motion seismograph at the Pumping Plant.

Civil Features

Preliminary Studies

Design of Oso Pumping Plant was prepared under contract by Bechtel Corporation of San Francisco. This contract included design of the intake transition, plant structure and equipment, discharge conduits, and outlet structure at the beginning of Quail Canal. Most of the preliminary studies and design criteria were furnished by the Department of Water Resources. Any departure from the original criteria had the approval of the Department.

Site Development

The major site development work was bowl excavation for the plant and intake canal and open-cut excavation for the discharge pipelines system.

Average depth of bowl excavation was about 75 feet from original ground surface. Bowl dimensions in the east-west directions are 570 feet at the bottom and 730 feet at the top. They are 450 feet at the bottom and 550 at the top in the north-south direction. Cut slopes in the main bowl are $2\frac{1}{2}$:1 with 20-foot-wide benches at 32- and 40-foot intervals vertically.

Surface runoff is collected on the berms in ditches and drained into the intake transition by means of corrugated-metal pipes. In the area of the siphon outlet, the surface runoff is collected by V-shaped dikes into catch basins and drained by corrugated-metal pipe and lined ditches. The north slope of the siphon embankment and adjacent areas are drained by a shotcrete-lined interception ditch which crosses over the discharge lines.

Plant Structure

General. The plant is an indoor type with three unit bays: two bays house two large pumps each, and one bay houses four small pumps. The service bay and control room are located at the east end of the plant. The structure is 341 feet long, substructure 85 feet wide, superstructure 63 feet wide, and overall height 104 feet. The height from the centerline of the distributor to the motor floor is 33 feet and from the motor floor to the top of crane rail is 25 feet (Figures 759 and 760).

Figure 759. Exterior View

Figure 760. Interior View

Design Criteria. Basic design criteria are discussed in Chapter I of this volume. They include the various codes, design loads, loading combinations, and other important structural data.

Seismic design of the plant structure was in accordance with the criteria contained in Chapter I of this volume except for stability of the plant foundation. The foundation could be subjected to small displacement resulting from excessive strains in the soil structure during several stress cycles when ground motion approaches peak acceleration of 0.5g.

Recognizing the fact that the duration of strong shaking involves a limited number of pulses approaching peak acceleration, it was decided that:

1. Foundation would be designed for an equivalent horizontal static force of 0.2g and, under this loading, the structure would not experience any displacement.
2. Lateral loads resulting from pulses exceeding 0.2g, and particularly those approaching 0.5g, could cause excessive soil stresses with the consequent possibility of displacement of the plant structure.

Special articulation between the plant structure and discharge conduits was designed to accommodate such a displacement, and no damage should occur to either structure.

If significant displacement occurs during a major earthquake, the articulation assembly will be readjusted to maintain the original degree of flexibility.

Foundation Stability. This plant was designed with a minimum factor of safety of 3 for all normal foundation loading conditions. A factor of safety of 1.1 against sliding was used for the unusual conditions of seismic loading.

Substructure. The substructure configuration was defined by the pump submergence and the 135-degree, suction-tube, elbow requirements. The resulting V-shaped structure provides an effective key into the foundation soil. Each pump bay is separated from adjacent bays by means of expansion-contraction joints.

Superstructure. The entire length of the superstructure is built of rigid steel frames and metal siding. It is divided into four separate bays by expansion joints located directly over the substructure expansion-contraction joints.

Waterways

The waterway through Oso Pumping Plant consists of intake transition, suction tubes, pumps, and pump discharge lines. Installed equipment consists of trashracks and steel bulkhead gates on the intake side of the plant, pumps and discharge valves inside the plant, and siphons at the outlet structure.

Intake Transition. The intake transition is over 200 feet long and is located on the north side of the plant at the end of a horizontal bend in Oso Canal. The bottom width of the transition varies from 24 feet at the Canal to 202 feet at the plant. Vertical retaining walls were constructed in the immediate vicinity of the plant. The entire transition is concrete-lined.

An extensive pump-drainage system protects the intake from the high ground water table. This system must be activated before any dewatering can take place. It reduces excessive hydrostatic and uplift pressures on the walls and slab.

The intakes of the pump suction tubes have trashracks to prevent debris from entering the pumps. The intake trashracks were designed for a velocity of 2 feet per second through the bars and a differential head of 4 feet across the racks. The trashracks are stacked two high and extend from the bottom of the suction tube opening to above the maximum water surface. No storage space was provided, and they are removed only for maintenance.

Six structural-steel bulkhead gates are provided for dewatering of the suction tubes. The gates slide vertically into slots formed in the plant intake piers and are placed in and removed from the suction tube openings with a 10-ton gantry crane. When not in use, they are stored in vertical slots at the east end of the plant at the service bay.

Suction Tubes. The suction tubes bend up at an angle of 135 degrees to meet the forebay invert at the required elevation. This configuration dictated the shape of the substructure forming an effective key into the foundation soil.

The suction tubes are partly steel- and concrete-lined. The steel liners were fabricated from welded steel plates and embedded in the concrete. A dewatering outlet, which discharges into the plant drainage system, is provided at the low point of each tube.

Pump Discharge Lines. Water is lifted 231 feet from the Oso approach canal into Quail Canal through five main discharge lines. Each line is a 9-foot-inside-diameter, buried, prestressed-concrete, cylinder pipe. Total length of the discharge system, from valve tapers to siphon outlet, is 2,020 feet. The maximum design head, including allowance for hydraulic transients, is 285 feet.

The discharge line system is symmetrical. Four 625-cfs pumping units, Units Nos. 1, 2, 7, and 8, connect directly into discharge pipelines Nos. 1, 2, 4, and 5; and four 157-cfs pumping units, Units Nos. 3 through 6, are joined by a manifold into discharge pipe No. 3.

Main features of the design are the manifolds and encased pipes, main discharge lines, and siphon outlet.

Manifolds and Encased Pipes. Manifolds and encased pipes include all steel pipe between the pump discharge valves and the end of the concrete encasement, together with valve tapers, articulation sections, wye branches, bends, and concrete-encased pipes. Steel used in the pipe shells and reinforcing rings is ASTM A285-C firebox quality. Shell varies in thickness from $\frac{3}{8}$ to $\frac{1}{2}$ inch; the reinforcing plates are $1\frac{1}{2}$ inches thick on the small wye branches and 2 inches thick on the large one.

The articulation system, described in Chapter I of this volume, allows movement between the valve tapers and manifolds by use of short sections of pipe supported between pairs of sleeve-type couplings.

Steel pipe between the articulation sections and the main discharge lines is encased in reinforced concrete, which supports earth loads and also acts as anchorage for bends and expansions. The pipes from the four large pumping units enlarge at bends and converge to meet the four outside main lines. Pipes from the four small pumping units merge beyond the bends into the center main line through a manifold consisting of three symmetrical, 45-degree, wye branches.

Main Discharge Lines. The main lines begin downstream of the manifolds and encased steel pipes and are constructed of 9-foot-diameter, buried, prestressed-concrete, cylinder pipes. The laying length of each pipe section is governed by its weight. Sections with a concrete core thickness of $6\frac{3}{4}$ inches prior to wrapping are 24 feet long, and those with a core of $8\frac{1}{4}$-inch thickness are 16 feet long. Pressure-head ratings for the pipe sections vary from 100 feet to 275 feet, in 25-foot increments. The pipe also is rated for external loading depending upon the loads expected. Pipe sections under the pumping plant backfill have a maximum of 27 feet of earth cover, but most sections are rated for only 3 feet of earth cover. Articulation between prestressed-concrete, cylinder, pipe sections is provided by $\frac{3}{4}$-inch to 1-inch joints filled with elastic joint material instead of cement mortar.

Siphon Outlet. Since the water-level fluctuation in Quail Canal is small, a typical siphon outlet structure with a siphon breaker is provided instead of a gated structure. The siphon outlet consists of a concrete-encased siphon liner, a concrete round-to-square transition, an expanding transition, and an open transition. The upstream end of each siphon liner is con-

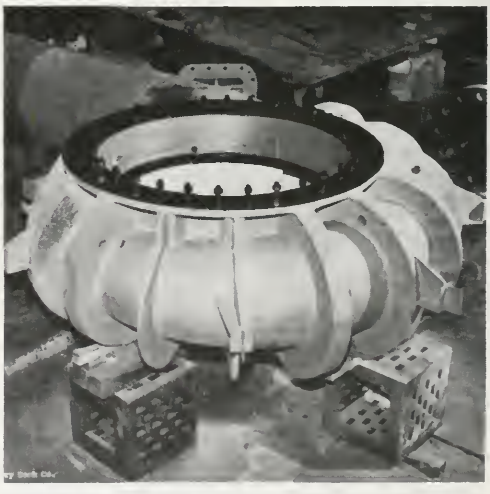

Figure 761. Preparing Pump Case for Shop Hydrostatic Test

nected to a prestressed-concrete cylinder pipe. There are stoplog slots at the downstream end of the expanding transition. Counterforted retaining walls are provided on each side of the open transition, with the warped surfaces starting as vertical walls at the beginning of the expanding transition and changing to a 2:1 slope at the first canal section.

Mechanical Features

General

The mechanical installation includes eight pumps, eight pump discharge valves, two equipment-handling cranes, and auxiliary equipment.

Chapter I of this volume contains information on mechanical equipment which is common to other plants in the State Water Project. Information and descriptions which are unique to this plant are included in the following:

Equipment Ratings

Main Pumps

Manufacturer: Newport News Shipbuilding and Dry Dock Co.

Type: Vertical-shaft, single-stage, centrifugal

Pumps Nos. 1, 2, 7, and 8

Discharge, each:	625 cfs
Total Head:	238 feet
Speed:	300 rpm
Guaranteed Efficiency:	91.5%
Minimum Submergence at Pump Centerline:	17 feet

Pumps Nos. 3, 4, 5, and 6

Discharge, each:	157 cfs
Total Head:	236 feet
Speed:	600 rpm
Guaranteed Efficiency:	92.5%
Minimum Submergence at Pump Centerline:	17 feet

Pump Discharge Valves

Manufacturer: Yuba Manufacturing Division of Yuba Industries, Inc.

Type and Size: Units Nos. 1, 2, 7, and 8—78-inch, metal-seated, butterfly
Units Nos. 3, 4, 5, and 6—36-inch, double-seated, spherical

Cranes

60-Ton Bridge Crane

Manufacturer: Crane Hoist Engineering and Manufacturing Co.

Type: Overhead, traveling, bridge

10-Ton Gantry Crane

Manufacturer: Broadline Corp.

Type: Outdoor, traveling, gantry

Pumps

Pumps are vertical-shaft, single-stage, double-volute, centrifugal type, directly connected to synchronous motors. All pumps rotate counterclockwise as viewed from the motor end.

Pump casings are embedded in the plant concrete substructure of the plant (Figure 761). The pump impeller, shaft, guide bearing and housing, and top casing cover are all removable from above when the motor rotor is removed (Figure 762). The hydraulic thrust and the weight of the rotating parts are carried by a motor thrust bearing.

Impellers are one-piece, enclosed, centrifugal, single-suction type, fabricated from cast steel and are provided with corrosion-resistant steel wearing rings.

Removable and renewable wearing rings are located in the suction and casing covers opposite the wearing rings on the impeller crown and band and are made of ASTM A276, Type 410, heat-treated stainless steel. The pump guide bearing is the self-lubricating skirt type.

Units Nos. 1, 2, 7, and 8 were designed to be started with the water depressed, while Units Nos. 3, 4, 5, and 6 were designed to be started in the completely watered condition. All embedded piping necessary for depressed starting of Units Nos. 3, 4, 5, and 6 was installed and stubbed out of the concrete for future use, if required.

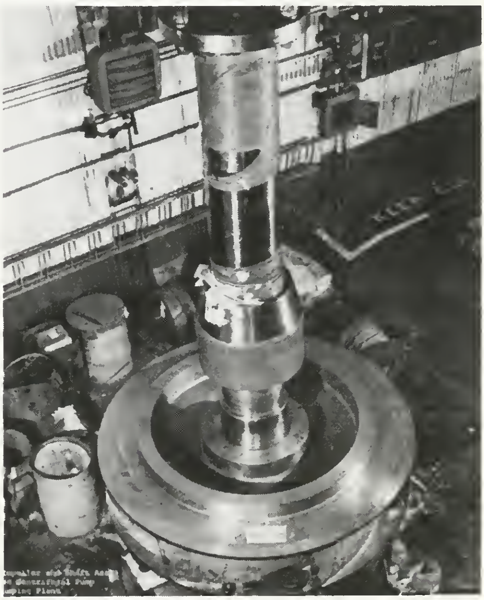

Figure 762. Pump Shaft-Impeller Assembly

Figure 763. 78-Inch Butterfly Valve

Figure 764. Discharge Valve Control Equipment

Neither lifting of the rotating parts when the water in the pump case reached the impeller nor floating of the rotating parts at shutoff head was experienced on these pumps during start-up.

Pump Discharge Valves

A pump discharge valve was installed on the discharge side of each centrifugal pump. These valves are used as a shutoff to prevent backflow through the units when they are stopped and to isolate each pump from its discharge line for inspection and maintenance.

Valves and appurtenances are located in valve vaults at the end of the discharge extension of each pump casing. Units Nos. 1, 2, 7, and 8 have 78-inch-diameter butterfly valves (Figure 763), each weighing approxiately 27,000 pounds; Units Nos. 3 through 6 have 36-inch-diameter spherical valves, each weighing approximately 14,000 pounds.

The operating mechanism for each valve is basically composed of an operating cylinder, piston, piston rod, cross-head, connecting linkage, locking device, and operating lever. The cylinder is double-acting, with the control system designed to simultaneously vent one side of the cylinder to the oil sump tank and allow oil to enter the other side under high pressure from the accumulator tank. The rate of valve movement is controlled by a metering valve on the discharge side of the cylinder.

Each valve plug or disc is rotated by its individual hydraulic system, pressurized by an air-over-oil accumulator. Each system, operating at a pressure of 500 pounds per square inch (psi), is capable of one opening cycle and two closing cycles, after which system pressure is reduced to 375 psi. Equipment in each system includes an oil accumulator, oil sump tank and pumps, and air compressor. Also included are directional and flow control valves; hydraulic control panel; valve control center; and necessary piping, wiring, and instruments. The air compressor and two hydraulic oil pumps supply air and hydraulic fluid, respectively, to the accumulator. The compressor and pumps normally are operated automatically but can be operated manually from the valve control center (Figure 764).

Seats on the 36-inch spherical valves (Units Nos. 3, 4, 5, and 6) are oil-operated and are located upstream and downstream of the transverse centerline of the valve. Seals are so arranged that either the upstream or downstream ring can be moved independently. The upstream seat is used as an operating seat, and the downstream seat is maintained in the open position and used as a shutoff valve when maintenance is required on the operating seat or on the main pumps. Opening and closing of the valve are controlled by a mechanical-electrical sequencer using cam-operated switches and hydraulic valves. The cams are mounted on a shaft which is driven by a 125-volt direct-current motor. The motor is controlled by a reversing starter whose forward and reverse contactors are energized and deenergized by plug and seat-limit switches and the cam-actuated switches previously mentioned.

The butterfly valves, Units Nos. 1, 2, 7, and 8, have bodies fabricated from forged steel flanges and steel plate, with the inner surface machined through. The discs are streamlined with smooth exterior surfaces and are secured to the one-piece shaft by four tapered pins. The minimum flow area is approximately 65% of the flow area based on the nominal size of the valve.

Valve bodies have monel seats that are adjustable from the outside of the valve body, and the discs have silicon bronze seats that are bolted to their edge.

Each pump discharge valve is operated only in the fully open position during normal pumping and will open or close at near uniform rate with the closing times being equal for normal or emergency conditions. All valves are set to close in approximately 28 seconds.

Equipment Handling—Cranes

Assembly and maintenance of major pumping plant equipment, including pumps, motors, and discharge valves, are serviced by means of a 60-ton, indoor, bridge crane. The plant also has a 10-ton, outdoor, gantry crane used to raise, lower, and transport the intake bulkhead gates. This crane was designed so that trashrack raking equipment could be added in the future.

The bridge crane is an electric, cab-operated, overhead, traveling type with a main 60-ton-capacity hook and an auxiliary 10-ton-capacity hook. A sister-type hook, bored for a lifting pin, is provided on the main hoist. The rated capacities and speeds of the bridge crane are:

Rated capacity, tons	60
Number of trolleys	1
Rated capacity of main hoist, tons	60
Rated capacity of auxiliary hoist, tons	10
Maximum lift, main hoist, feet—inches	69′—6″
Maximum lift, auxiliary hoist, feet—inches	69′—6″
Hook, Speeds—feet per minute (fpm)	
Main (5 step)	0–3
Aux. (5 step)	0–17
Bridge speed—fpm	95–100
Trolley speed—fpm	40–50

Brakes are provided for hook, trolley, and crane travel. They include both the electric and hydraulic shoe type, with shunt coil and manual release lever. The bridge crane is controlled from the operator's cab mounted below one corner of the crane.

Access to the cab is provided at two locations from platforms located at either end of the building on the discharge side of the plant. The operator's cab is provided with an extension-type access ladder with a counterbalance mechanism for emergency conditions.

The 10-ton gantry crane is an outdoor traveling type with provision for a trashrack rake. It operates on steel rails in the plant gate deck (Figure 765). The lifting mechanism consists of a lifting beam suspended from twin snatch blocks. Rated capacities and speeds of the gantry crane are:

Rated capacity, tons	10
Number of trolleys	1
Rated capacity of hoist, tons	10
Span, feet—inches	11′—5″
Hoist speed with maximum working load, fpm (two speeds)	12 and 3
Gantry travel speed with maximum working load, fpm	35
Trolley travel speed with maximum working load, fpm	4
Maximum lift, feet	40

Hydraulic Transients

Surge and reverse speed control is provided by single-speed discharge valve closure. The calculated upsurge, downsurge, and reverse-speed conditions with the single-speed closure of 28 seconds were well within the design limits of the equipment. Field tests of simulated power failures have verified the calculated results.

Auxiliary Service Systems

The auxiliary service systems at the plant are described in Chapter I of this volume. Items unique to this plant are discussed in the following sections.

Raw Water System. Raw water is drawn from the main discharge lines just downstream of the pump discharge valves at Units Nos. 1, 2, 3, 7, and 8.

Water Fire-Extinguishing System. A fire pump is located in the service bay and is started manually. It is used primarily to provide additional pressure when hoses are connected to hydrants to control grass fires around the edge of the plant bowl.

Coupling Gallery Hoist. A 3-ton monorail hoist is provided in the discharge pipe coupling gallery to handle the suspended pipe section of the discharge line. The trolley is operated from the walkway located above the discharge lines on the north side of the gallery. The hoist is operated from the floor of the coupling gallery.

Figure 765. 10-Ton Gantry Crane

Figure 766. 4,700-Horsepower Synchronous Motors

Figure 767. Transformer Yard

Figure 768. 480-Volt Station Service Substation

Electrical Features

General

The electrical installation includes a 66-kV switchyard; power transformers; motors; switchgear; and auxiliary systems for station service, communication, and protection of equipment and personnel.

Chapter 1 of this volume contains information on electrical equipment and systems for Oso Pumping Plant which also are common to other plants in the Project.

Description of Equipment and Systems

The motors are operated from the 13.6-kV system. The smaller motors are started full-voltage, across-the-line, with water in the pump case (Figure 766). The larger units are started from the reduced-voltage connection of the power transformers and with water depressed below the pump impeller. The motors are wye-connected with the neutral grounded in series with the high-voltage winding of a distribution transformer. A resistor is connected across the transformer low-voltage winding. The transformer-resistor combination limits phase-to-ground fault current and also is utilized to detect abnormal ground currents for tripping the motor circuit breaker. Surge equipment, consisting of lightning arresters and capacitors, is provided in the line side of the motor to protect it from transient overvoltages caused by lightning or switching surges.

Two power transformers are provided to reduce voltage from 67.5 kV to 13.6 kV to operate the motors and provide power to the station service system (Figure 767). Transformers also have a 6.8-kV tap to provide voltage for starting the four large motors.

The 66-kV switchyard was designed to utilize a main-and-transfer bus arrangement. Four bays provide switching and protection for the transmission line, two load lines to the Pumping Plant, and one transfer bay for connecting the two buses.

Lightning arresters were installed at the transmission line connection to the switchyard and at each transformer. Revenue metering is located in the transmission line bay and measures power supplied at 66 kV.

A 13.6-kV system supplies power to the motors and to the station service system. Nonsegregated-phase bus is used to connect the transformers to circuit breakers in each load feeder. Breakers interrupt the circuit to a motor or station service transformer in the event of abnormal conditions and also are used for normal switching of circuits to start or stop motors or control power to the station service transformer.

The double-ended station service substation contains two transformers to reduce voltage from 13.2 kV to 480 volts (Figure 768). Connected to the secondary bus are 480-volt feeder breakers for distribution of power to various motor control centers, power distribution centers, and lighting distribution centers located throughout the plant (Figure 769).

Switchboards were installed to house protective relaying, instruments, meters, annunciators, and the local control panel. These switchboards are provided for each pumping unit.

Pumping units and auxiliaries may be controlled from the control room. A computer control system was installed with complete facilities to control, monitor, log data, annunciate, and display all plant and switchyard requirements (Figures 770 and 771). In addition to operating the plant from the control room, equipment was installed to operate each unit in a local mode at its switchboard (Figure 772). A panel is provided on each switchboard to selectively start certain equipment until the full starting cycle is complete. Each auxiliary piece of equipment also may be started from motor control centers and distribution centers. Volume V of this bulletin describes the control system within the plant and the system which is remote.

Figure 769. 480-Volt Distribution Board


Figure 770. Control Room

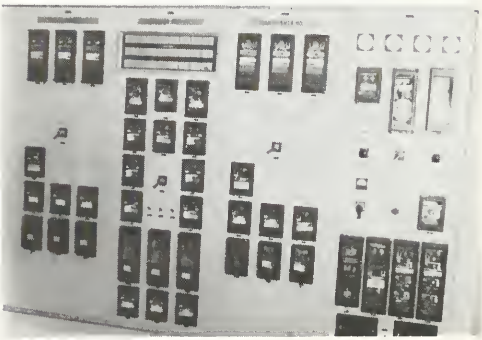
Figure 771. Control Room Relay and Control Panel

Equipment Ratings

Motors

Manufacturer: General Electric Company
Type: Vertical-shaft, synchronous
Power factor: 95%
Frequency: 60 Hz
Phase: 3
Volts: 13,200

Motors Nos. 1, 2, 7, and 8

Horsepower: 18,750
Speed: 300 rpm

Motors Nos. 3, 4, 5, and 6

Horsepower: 4,700
Speed: 600 rpm

Power Transformers

Manufacturer: Federal Pacific Electric Company
Volts: 67,500/38,972-13,600/6,800
Taps: In the high-voltage winding, 2½ and 5% above and below rated voltage
Phase: 3
Frequency: 60 Hz
kVA: 28,500/38,000
Type: OA/FA
Connection: Wye-Delta

Station Service

Number of transformers: 2
Volts: 13,200—480Y/277
Phase: 3
Frequency: 60 Hz
kVA: 500
Type: AA
Emergency engine-generator: 100 kW, 480Y/277 volts, 3 phase, 60 Hz

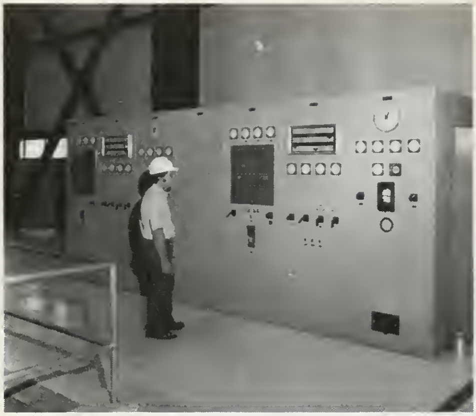

Figure 772. Unit Control Board

Figure 773. 66-kV Switchyard

Figure 774. 66-kV Oil Circuit Breaker

High-Voltage Service

Oso Pumping Plant is connected to a single 66-kV transmission line. Although all other major pumping plants in the Project are supplied by one or more 220-kV lines, 66 kV was acceptable at this plant since it was adequate for the load and the line is only 5 miles long. The relatively short distance from the substation and ready accessibility for maintenance by the utility company made the single line acceptable from the standpoint of reliability.

66-kV Switchyard

The switchyard was designed with a main and transfer bus (Figure 773). This arrangement required two bays for the lines to the transformer loads: one bay for the utility transmission line, and one transfer bay. One circuit breaker was installed in each bay to interrupt the transmission line or load lines in event of faults in the plant or on the line. Breakers also serve for use in maintenance of lines and equipment and for normal switching operations. The one breaker in the transfer bay is to be utilized whenever one of the other three breakers is removed from service for inspection or maintenance. The transfer breaker provides protection to the transmission or load lines during that period. A disconnect switch is provided on each side of the circuit breakers to be opened during maintenance of the circuit breaker.

This switchyard arrangement was selected because of its flexibility for future additions. Cottonwood Powerplant, a small power recovery plant, is planned for construction on the "main line" California Aqueduct in the vicinity of Oso Pumping Plant. It is expected that the Cottonwood Powerplant output will be connected to the switchyard at Oso Pumping Plant.

The 66-kV circuit breakers were specified to be oil breakers rather than air or gas breakers, which are used in most of the other switchyards (Figure 774). The reason for the selection of oil was the lesser cost of oil breakers at the time of bidding. Oil-handling facilities are not necessary due to the relatively small amount of oil in breakers of this size.

Motor Starting Method

The 4,700-horsepower motors are started with full voltage and the pump case watered, while 18,750-horsepower motors utilize a reduced-voltage start with water depressed below the impeller. Since the motors are started daily for off-peak pumping, consideration was given to designing a starting system which would not require extensive maintenance on the motors.

Four starting methods were studied for the larger motors:

1. Neutral reactor for each motor.
2. Starting bus for each transformer with group reactor.
3. Starting bus for each transformer with transformer voltage tap.

4. Full-voltage watered start.

Studies concluded that a starting bus with a voltage tap in the power transformer was the most advantageous. Costs and space requirements were minimal for this system. The ratio of motor starting torque to motor starting kVA is higher than when a reactor is used. Starting kVA was kept below the requirements of the utility company, with reduced-voltage start on the large units and full-voltage start on the smaller motors. Full-voltage watered start for the small motors was selected mainly for economics and simplicity. Less equipment for starting motors was required, and the need to depress water was eliminated. Due to the relatively low horsepower, it was concluded that stresses on the mechanical parts and windings during starting would not be excessive.

Full-voltage watered start for the larger units was most reliable since it required a minimum of auxiliary equipment. Limits set by the utility company, however, could not be met by this starting method, and it was abandoned.

Construction

Contract Administration

General information about the major contracts for the construction of Oso Pumping Plant is shown in Table 15. The site development comprising excavation of the approach canal, pumping plant bowl, and discharge lines; construction of compacted embankment; construction of roads; and installation of a drainage system were done under the provisions of Specification No. 67-07. Construction of the Pumping Plant and discharge lines was accomplished under Specification No. 67-60, and the Pumping Plant was completed under Specification No. 69-09, which contract included the installation of the major mechanical and electrical equipment.

Figure 775. Site Development

Excavation

Most of the excavation for the Pumping Plant was accomplished under the site development contract, Specification No. 67-07 (Figure 775). Work on this contract began March 10, 1967 and was completed November 15, 1967 without encountering any unusual problems.

TABLE 15. **Major Contracts—Oso Pumping Plant**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Oso Pumping Plant site development	67-07	$447,843	$472,713	$12,419	3/10/67	11/15/67	W. E. McKnight Construction Company
Pumps	67-22	2,051,170	2,405,000 (Est.)	12,277*	7/ 8/67	11/20/73	Newport News Shipbuilding & Dry Dock Co.
Bridge cranes (including Buena Vista, Wheeler Ridge, and Wind Gap Pumping Plants)	67-57	423,850	453,676	10,622	12/13/67	10/13/69	Crane Hoist Engineering & Mfg. Co.
Oso Pumping Plant and discharge lines	67-60	7,125,169	9,084,020	1,242,285	12/29/67	1/31/72	Stolte, Inc. & Santa Fe Engineers, Inc.
Oso motors	67-61	2,347,010	2,869,298	28,029	1/ 8/68	12/17/73	General Electric Co.
Valves	68-02	896,956	986,053	3,502	3/15/68	3/15/72	Yuba Industries, Inc.
Power transformers	68-18	185,371	195,307	−50	4/18/68	3/23/72	Federal Pacific Electric Co.
13.8-kV switchgear and station service	68-26	361,325	441,167	54,684	8/13/68	6/29/73	Golden Gate Switchboard Co.
Switchboards	68-33	202,110	234,986	22,085	3/10/67	10/ 1/70	Dietz Electrical Mfg. Co.
69-kV switchyard equipment	68-39	74,737	84,821	4,692	10/ 2/68	10/ 5/71	General Electric Co.
Completion of Oso Pumping Plant	69-09	2,049,000	2,170,520	125,966	7/11/69	6/16/72	Owl Constructors

* As of November 1974

Structural Excavation

Pumping Plant. Sixteen cased wells were installed around the perimeter of the pumping plant bowl before commencing structural excavation. The ground water removed by pumping was used in construction. Initial structural excavation began at elevation 3,108 feet and was made with scrapers and dozers. Side slopes were trimmed with a grader. When the excavation reached elevation 3,060 feet, excessive ground water was encountered and excavation was suspended while two additional wells were developed. After these wells dewatered the site, excavation was completed.

In the deepest excavation, which was for the plant sump at elevation 3,044 feet, lakebed deposits were encountered. The overexcavation resulting from removal of the lakebed deposits was backfilled to final grade with filter material.

Discharge Lines. Excavation for discharge lines below site development grade was made with a backhoe equipped with a curved bucket (Figure 776). A trench was excavated approximately 3 feet deep for each line. Bell holes at each pipe joint location in the pipe trench were excavated with the same backhoe equipped with a smaller bucket. Excavated material was hauled to the designated waste area.

Backfill and cover for the discharge lines came from waste piles, switchyard excavation, and canal excavation south of the outlet works. Sand was jetted and vibrated into bell holes. Material near the pipes was hand-tamped using whackers. A dozer was used to spread material over the discharge lines. Material was compacted with a compactor and a vibrating sheepsfoot roller. Moisture for this operation was maintained by use of water trucks.

Siphon Outlet Works. The outlet structure and appurtenances are founded primarily on embankment. Earth-moving equipment used for the discharge line also was used in the construction of the outlet works. Embankment materials were obtained from the Quail Canal channel excavation over an average haul distance of 1,200 feet.

Pneumatically Applied Mortar

Exposed excavation surfaces for the Pumping Plant were covered immediately with 2 inches of wet mix shotcrete to prevent deterioration pending final placement of concrete (Figure 777). The shotcrete surface also served as a working surface for subsequent concrete operations.

Concrete Placement

Concrete was produced by a central batch plant and mixer located on the job site near the pumping plant location. The concrete was transported to the area of placement on flatbed trucks, each carrying two 2-cubic-yard buckets equipped with pneumatic bucket busters and vibrators (Figure 778). These buckets were lifted from the trucks to the placement by tower cranes (Figure 779). After removal of the tower cranes, a truck crane and the pumping plant bridge crane were used for placement of delayed first-stage concrete.

Concrete was placed without difficulty. Extra care was taken when placing delayed first-stage concrete around pump casings and steel suction tube liners. Concrete was placed slowly and in small lifts which were brought up evenly on all sides with special attention given to good consolidation. Concrete was consolidated with air-driven immersion-type vibrators.

Figure 776. Excavation for Concrete Discharge Line

Figure 777. Preparing Load Bearing Surface With Wet Mix Shotcrete

Figure 778. 2-Cubic-Yard Concrete Bucket

Figure 779. Pumping Plant Construction—Note Tower Cranes

Consolidation was good and rock pockets were few.

Expansive grout was placed under base plates and injected into voids under the pump casings through holes provided for that purpose by the pump manufacturer.

Discharge Lines

Discharge line pipe tapers were delivered to the site by truck-trailers from the fabrication plant. The tapers were positioned and anchored in sequence with concrete placements and joined with expansion couplings. Fabricated bends and manifolds were positioned on reinforced-concrete foundations and anchored in place (Figure 780). A bell ring adaptor was welded on the ends for the transition to the reinforced-concrete discharge pipe. The manifold was pressure-tested at the site. Combined bends and manifolds were set in place with a tower crane and encased in reinforced concrete. The interiors of the manifolds were sandblasted and coated with coal-tar epoxy.

Electrical Installations

The electrical features for the Pumping Plant under Specification No. 67-60 were installed in a routine manner with a minimum of delays and changes.

These installations, required under the contract for completion of Oso Pumping Plant, Specification No. 69-09, were made by a subcontractor and were accomplished with few problems.

Mechanical Installations

The major mechanical installations were made by the contractor for completion of Oso Pumping Plant, Specification No. 69-09, and included installation of department-furnished pumps, motors, valves, compressed air system, water systems, fire-extinguishing systems, engine generator, and other equipment. Installations were made in a routine manner except for a short period in November 1970 when heavy rains flooded the lower part of the plant, necessitating the repair of some equipment.

Figure 780. Steel Discharge Manifold System During Erection of the Center Manifold Wye

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 781 through 810).

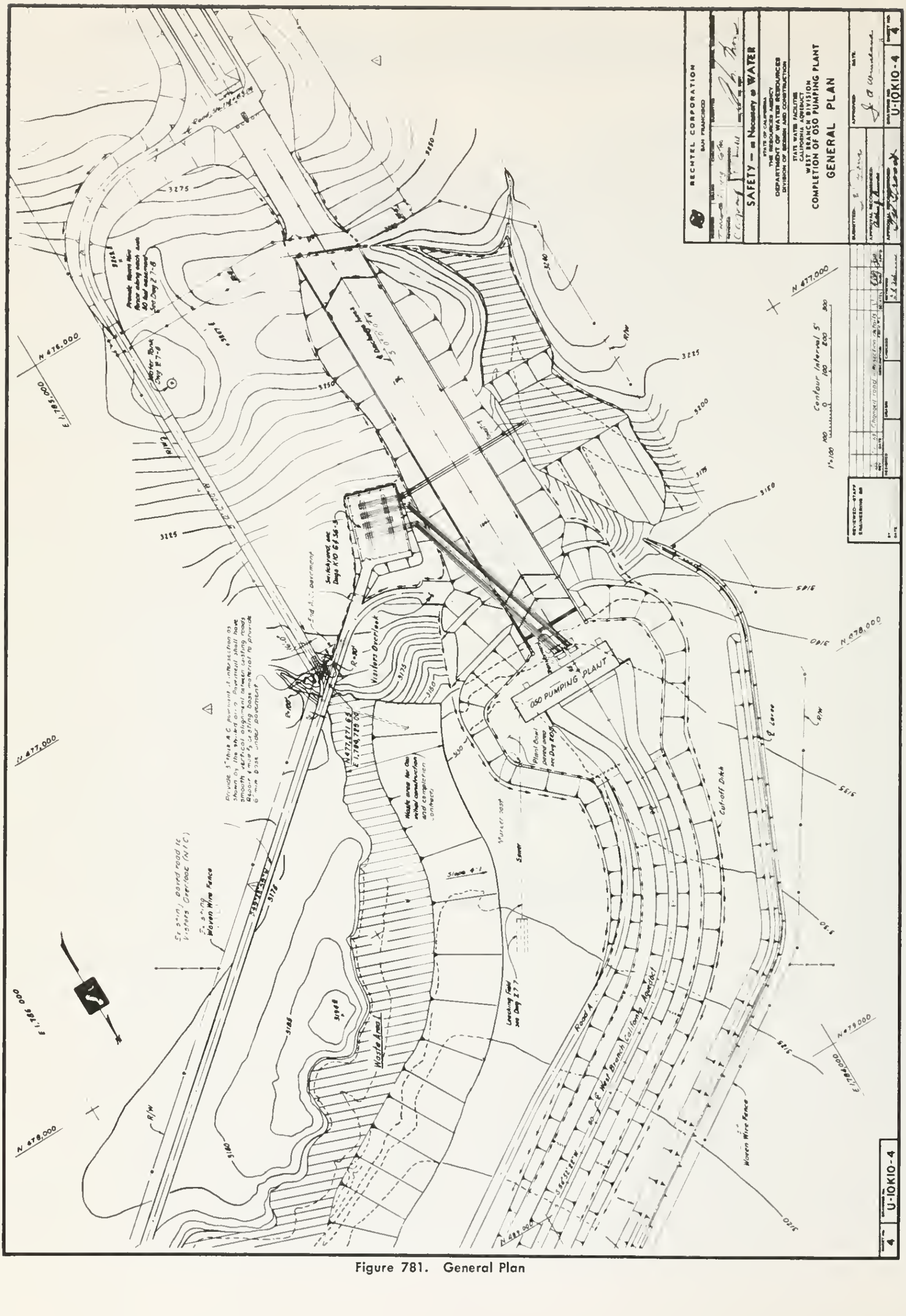

Figure 781. General Plan

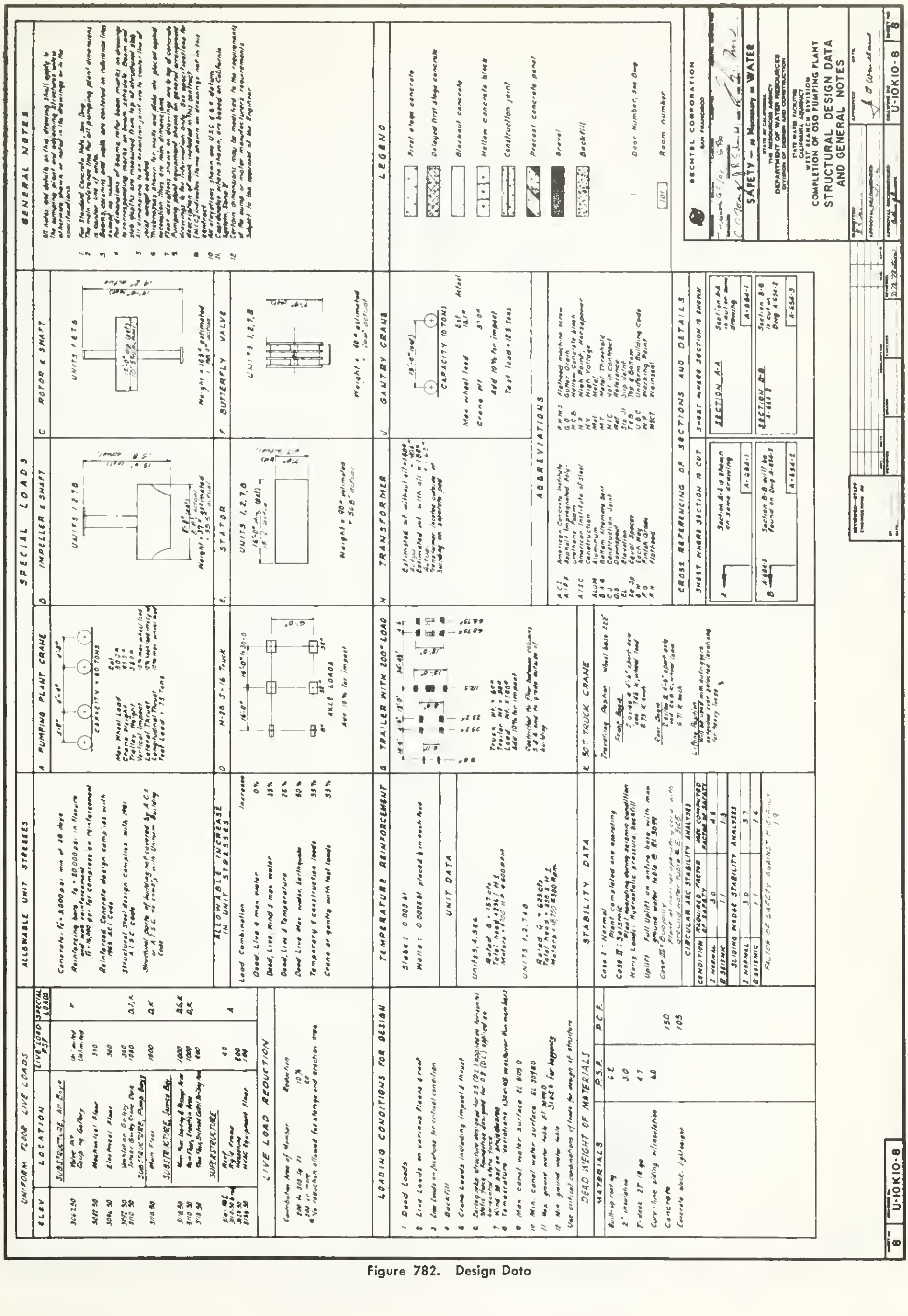

Figure 782. Design Data

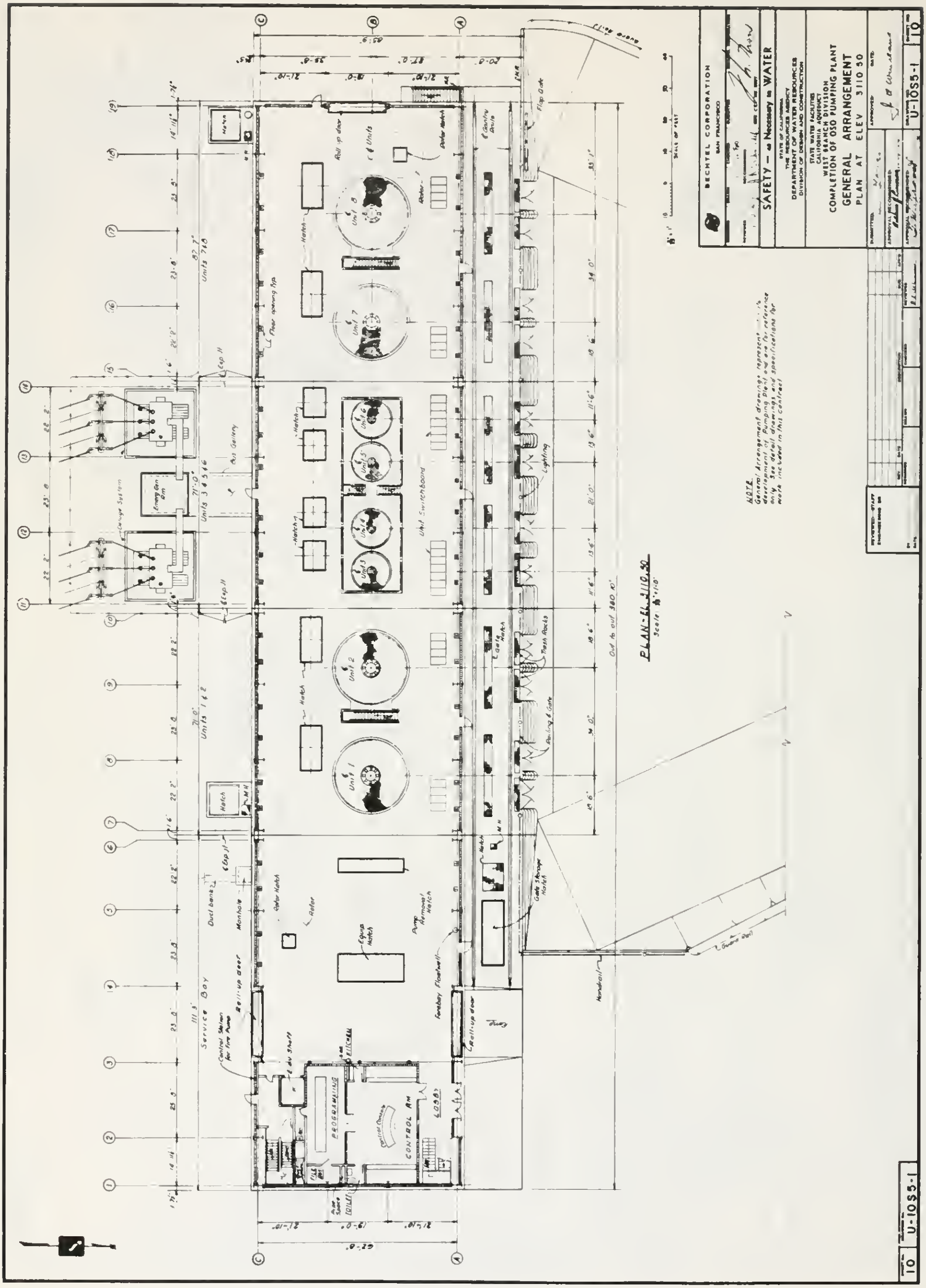

Figure 783. General Arrangement—Elevation 3,110.5

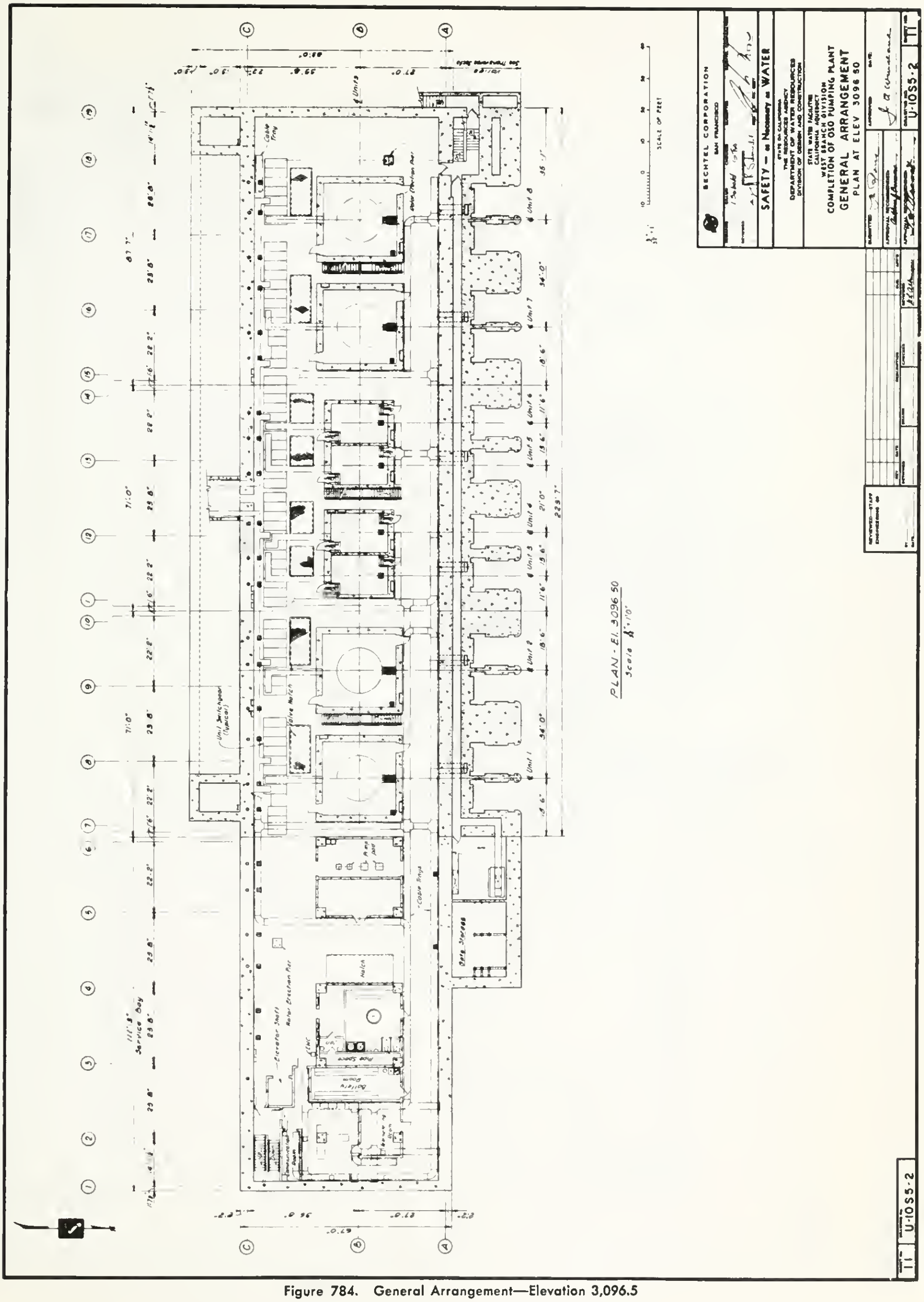

Figure 784. General Arrangement—Elevation 3,096.5

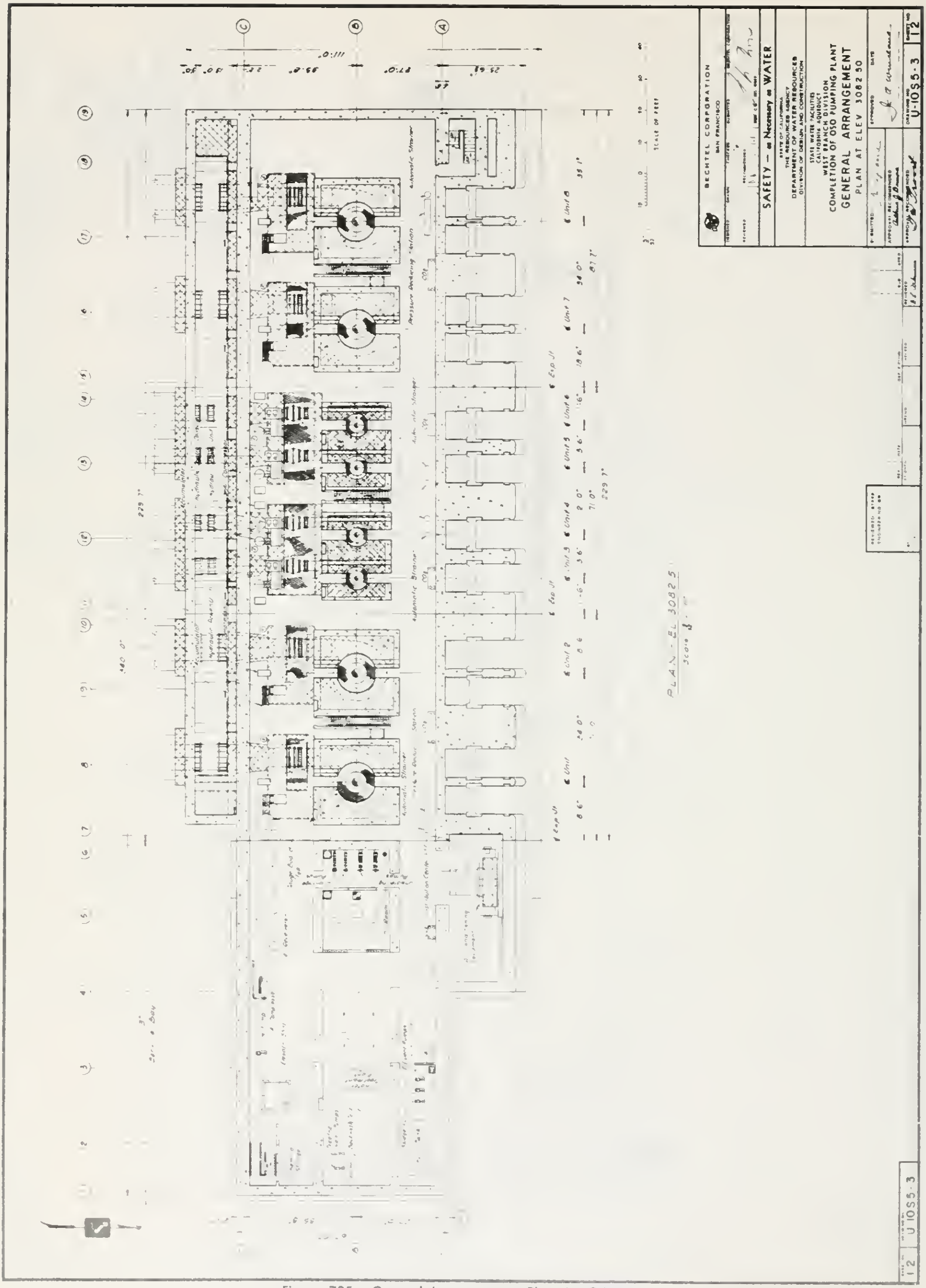

Figure 785. General Arrangement—Elevation 3,082.5

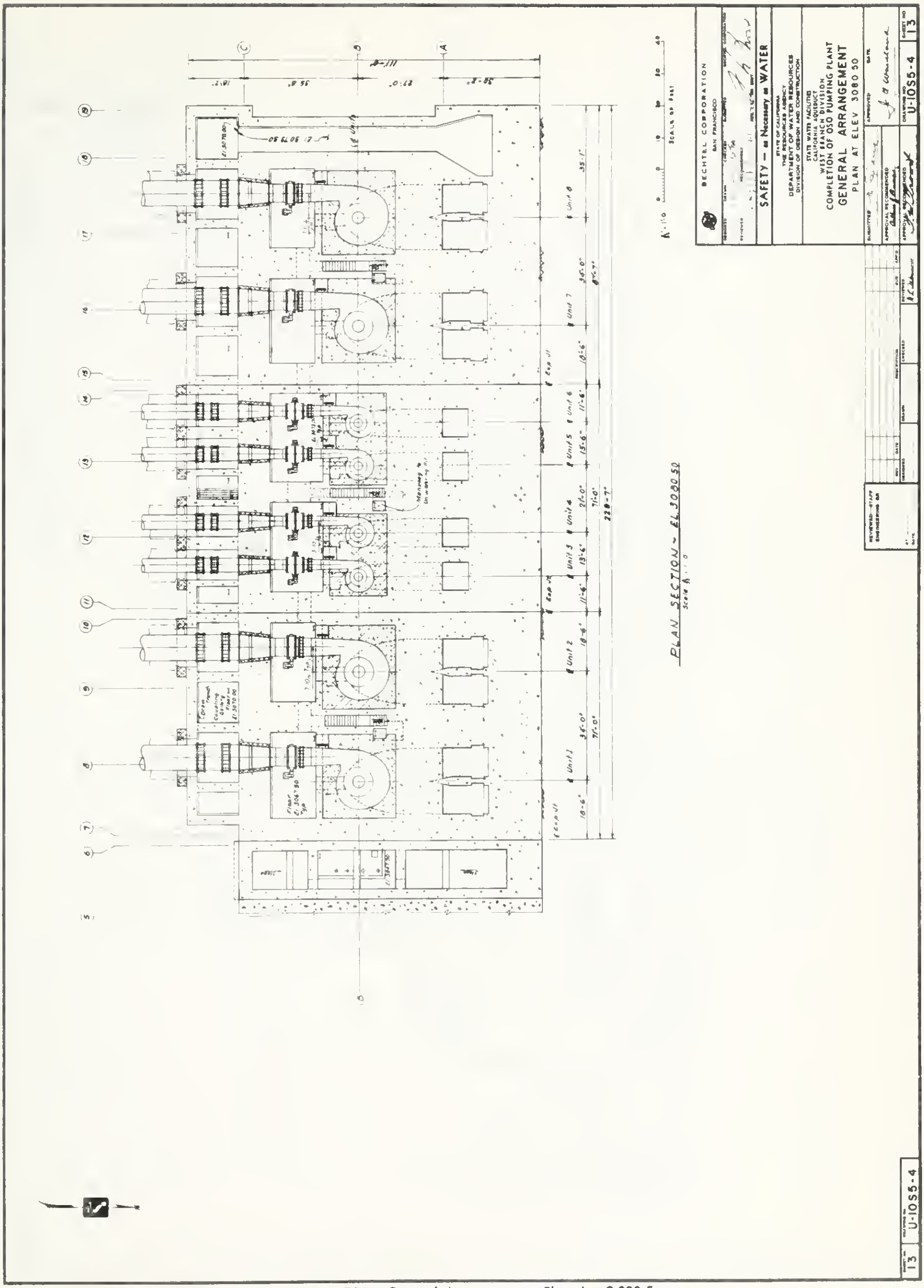

Figure 786. General Arrangement—Elevation 3,080.5

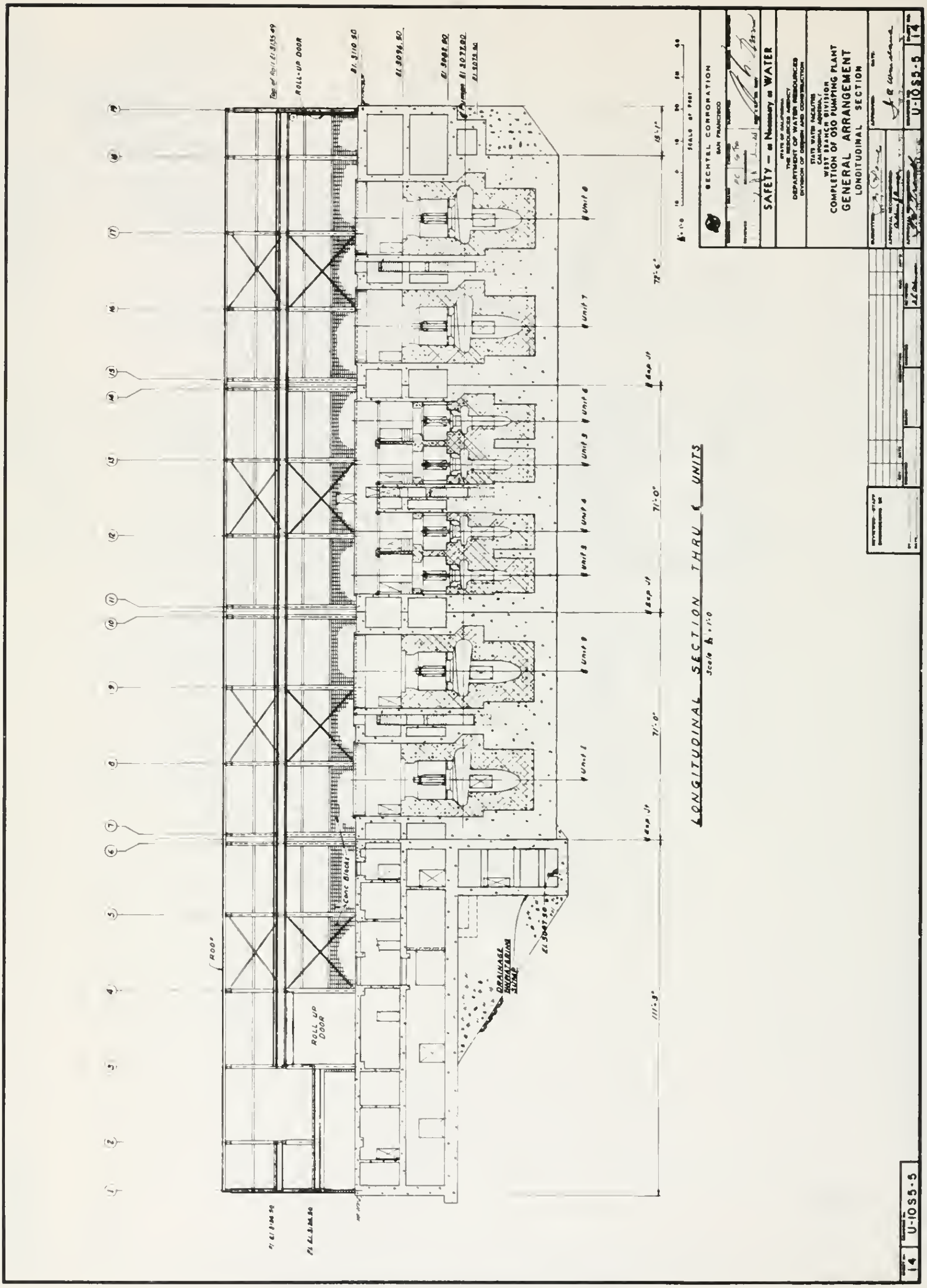

Figure 787. General Arrangement—Longitudinal Section

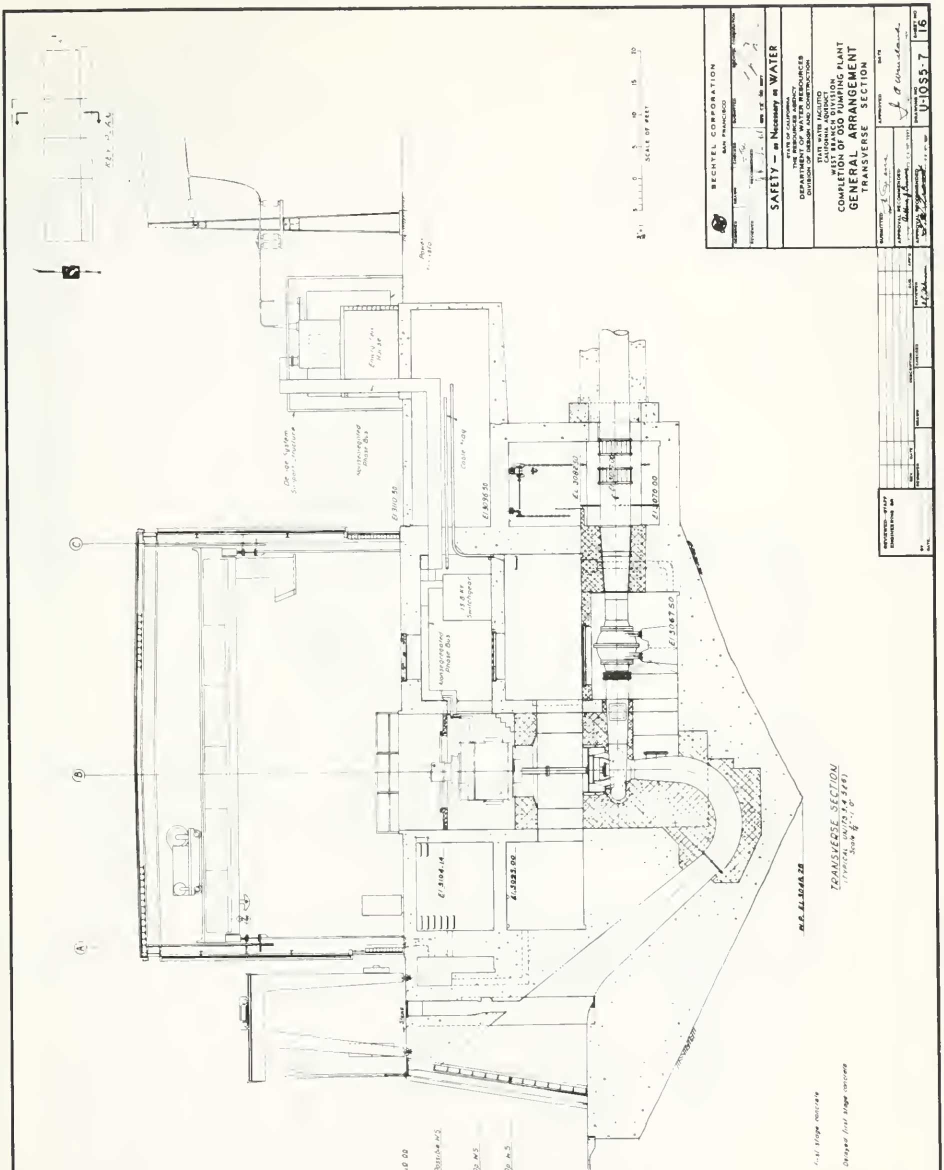

Figure 788. General Arrangement—Transverse Section Units Nos. 3, 4, 5, and 6

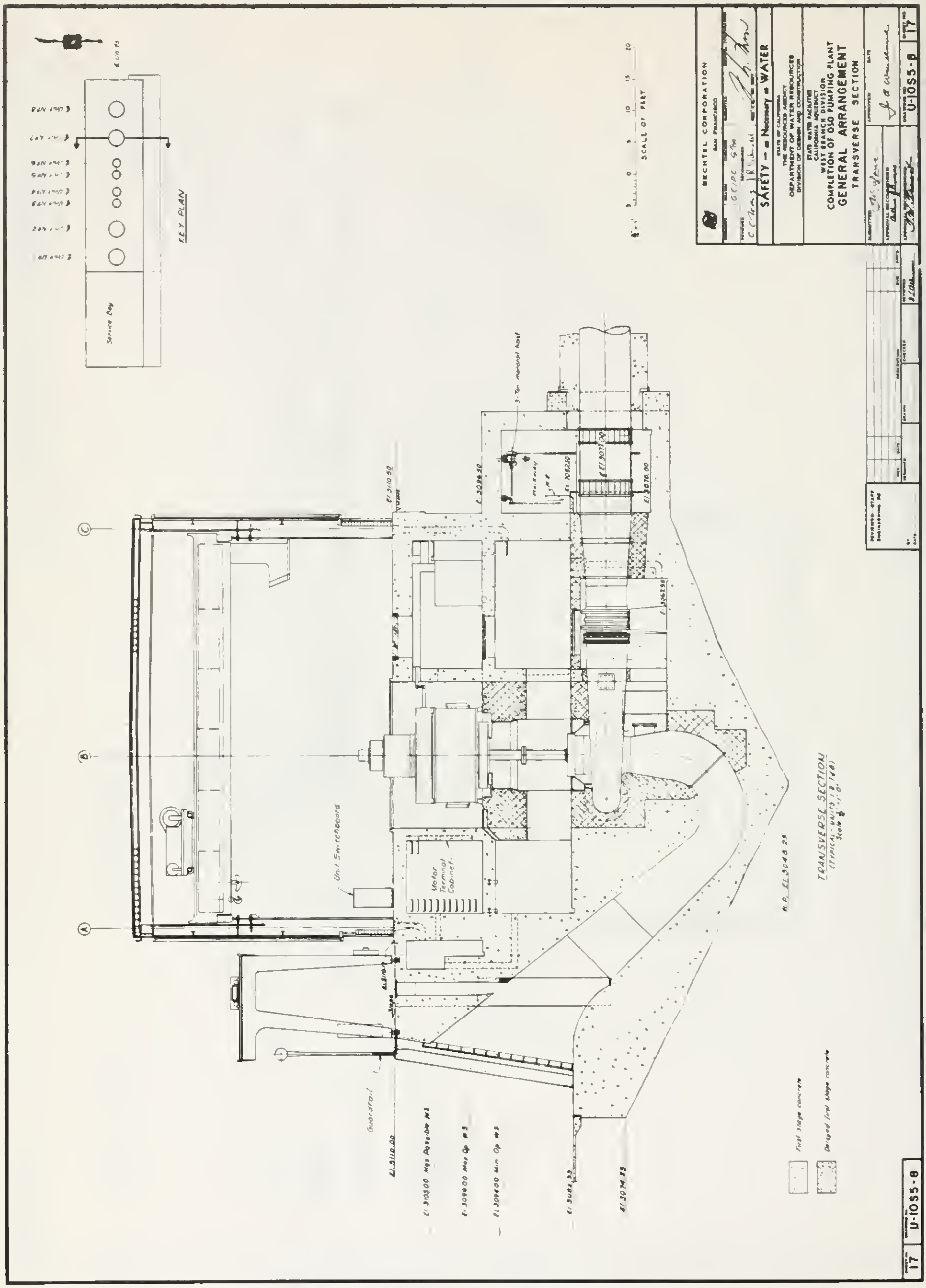

Figure 789. General Arrangement—Transverse Section Units Nos. 1, 2, 7, and 8

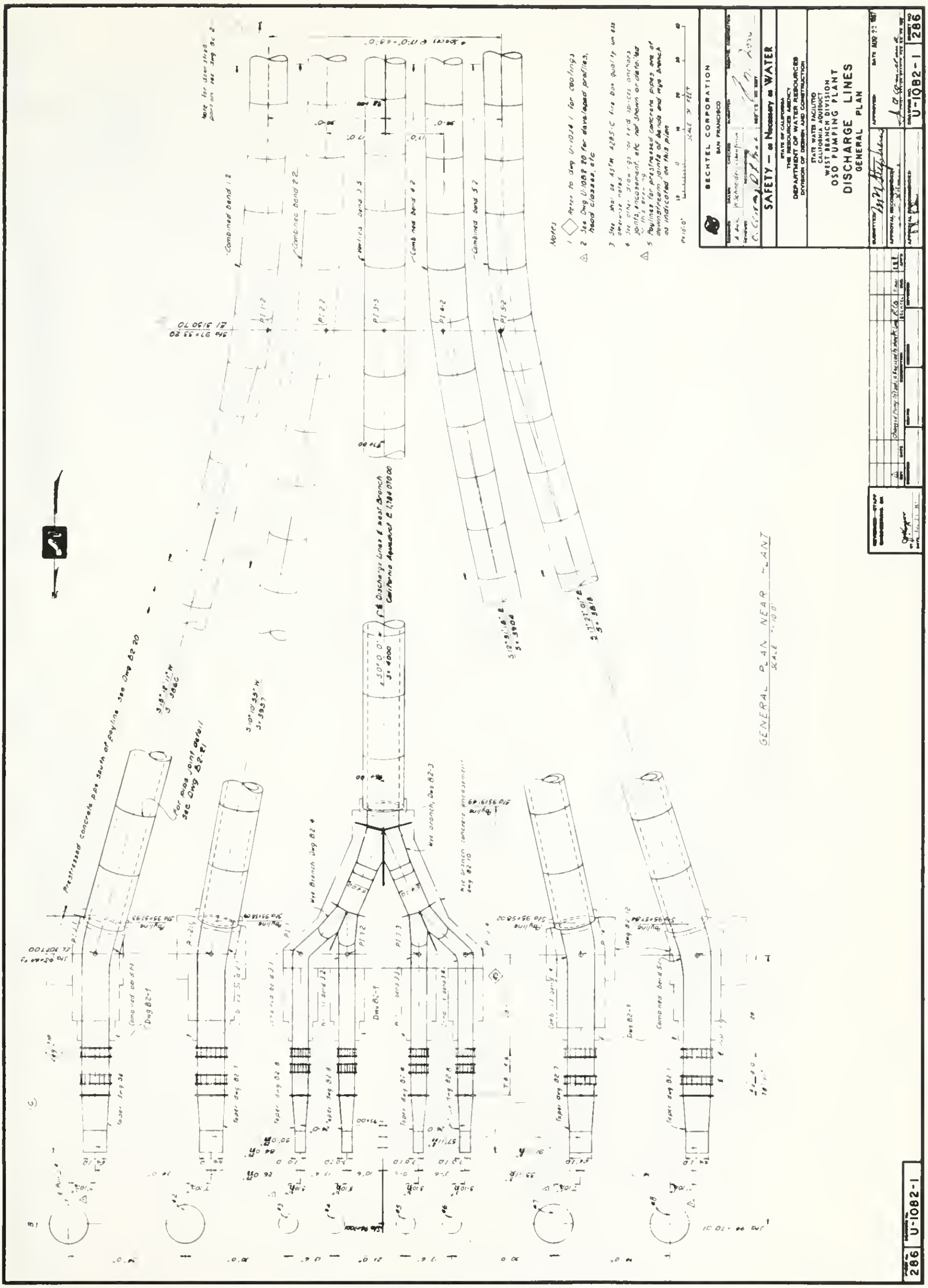

Figure 790. Manifolds—General Plan

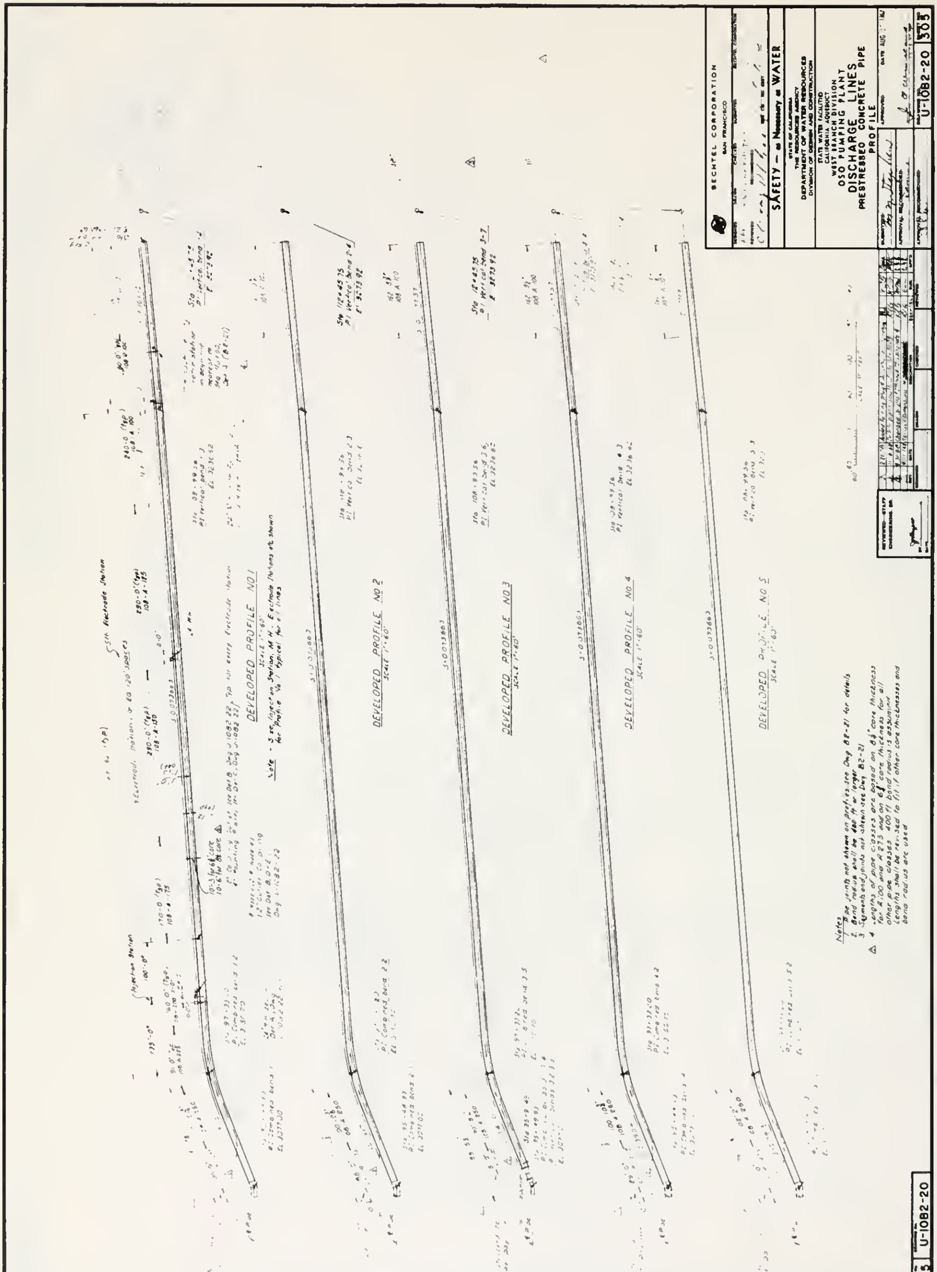

Figure 791. Discharge Lines—Profile

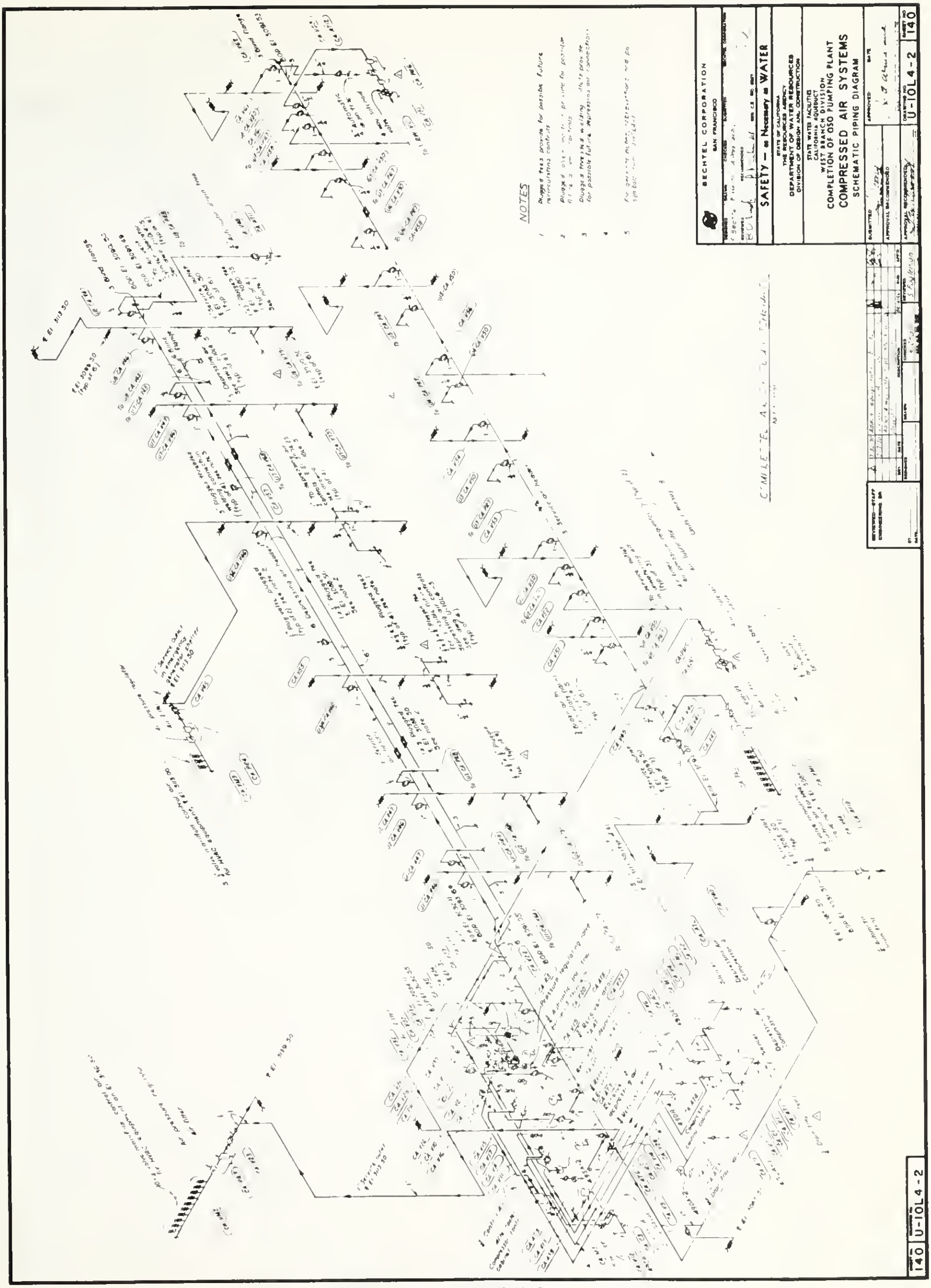

Figure 792. Compressed Air Systems

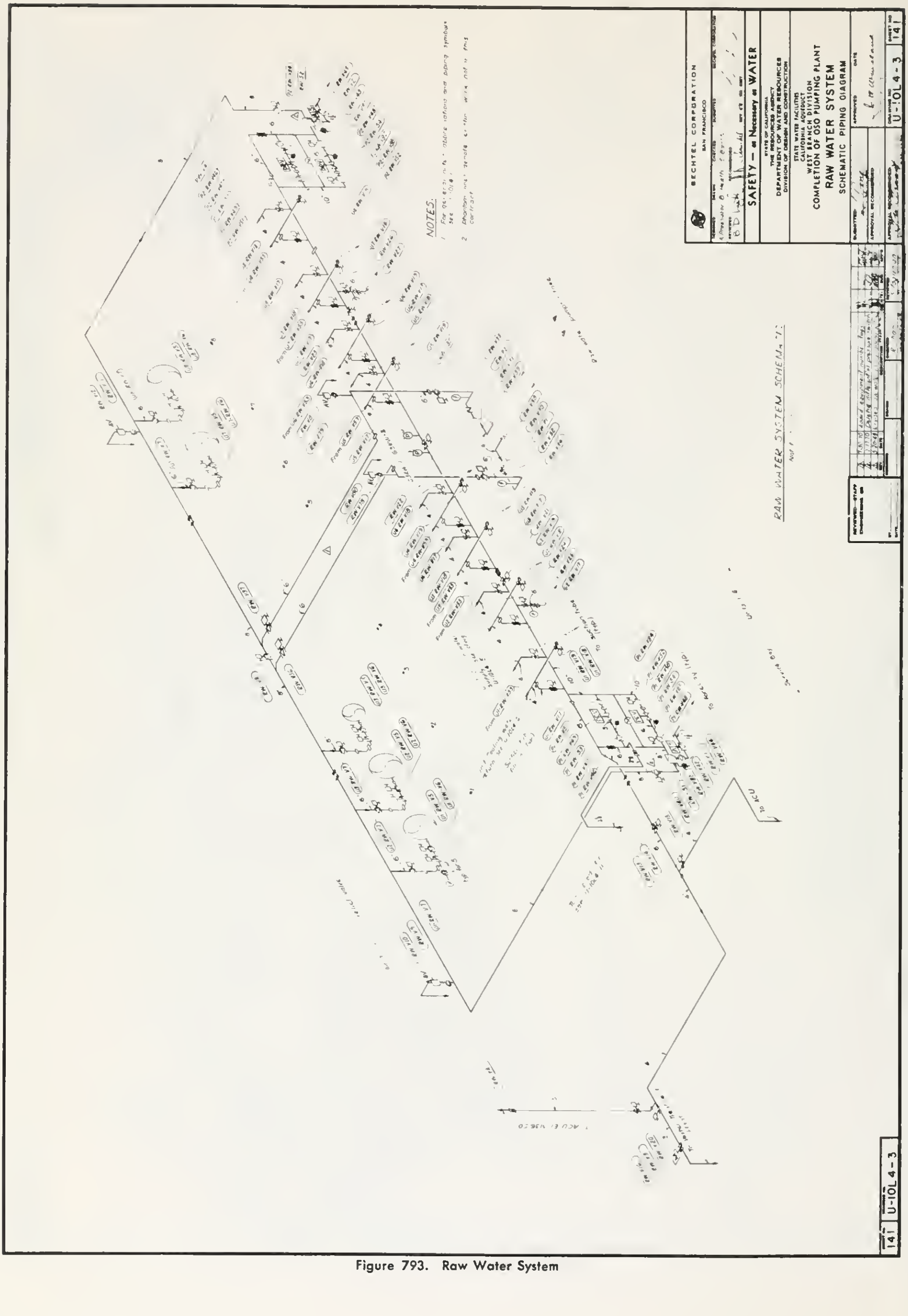

Figure 793. Raw Water System

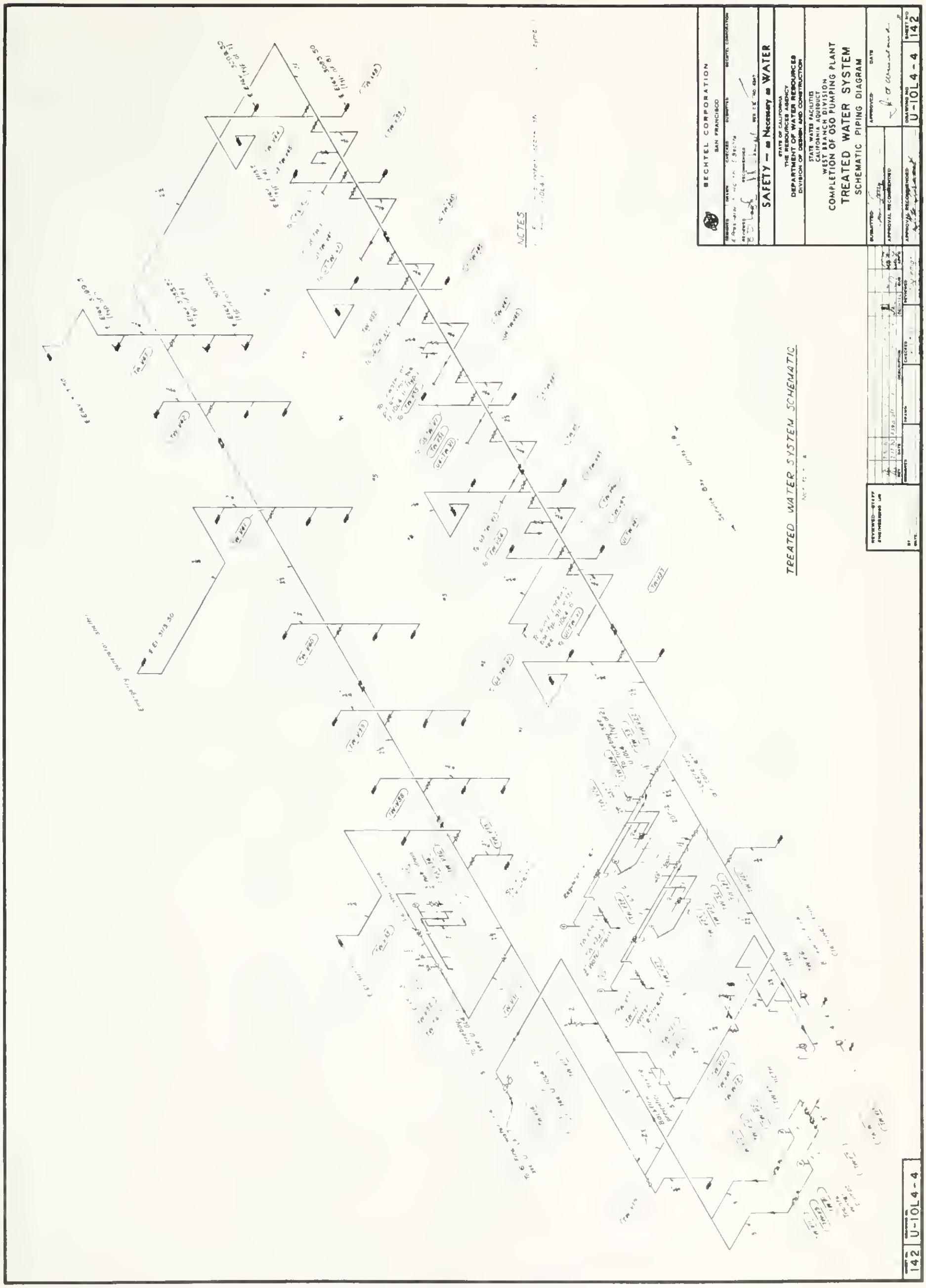

Figure 794. Treated Water System

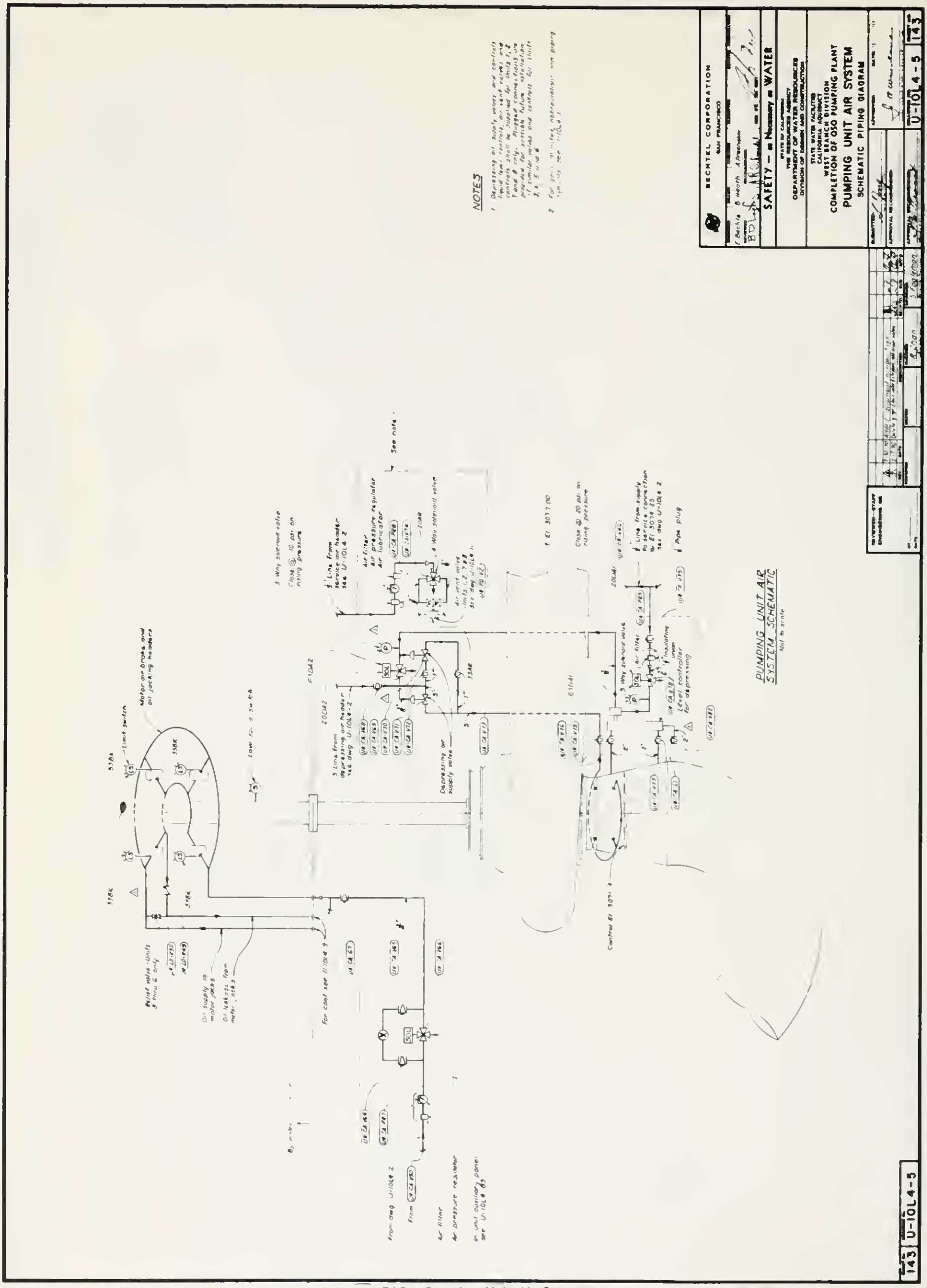

Figure 795. Pumping Unit Air System

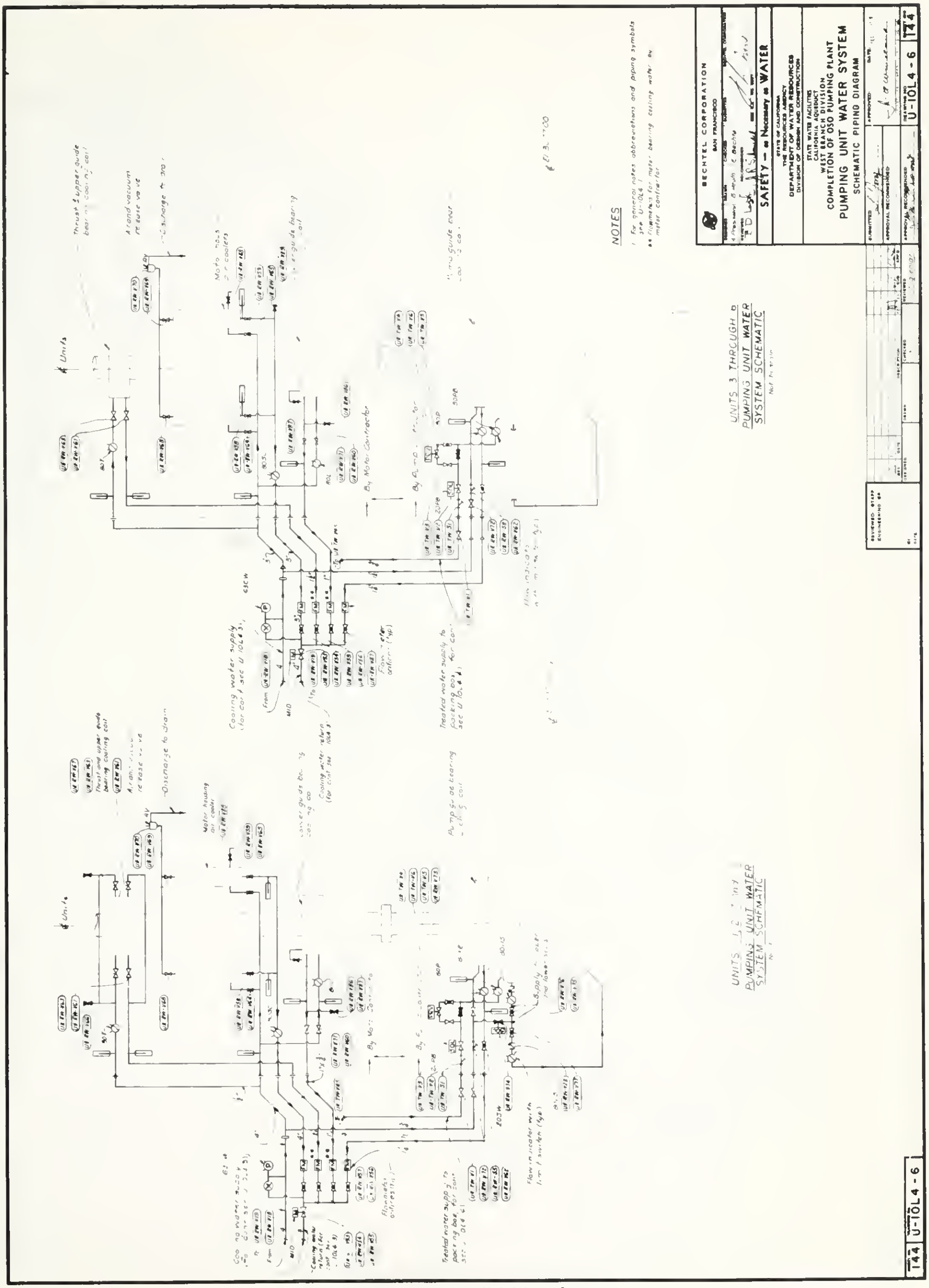

Figure 796. Pumping Unit Water System

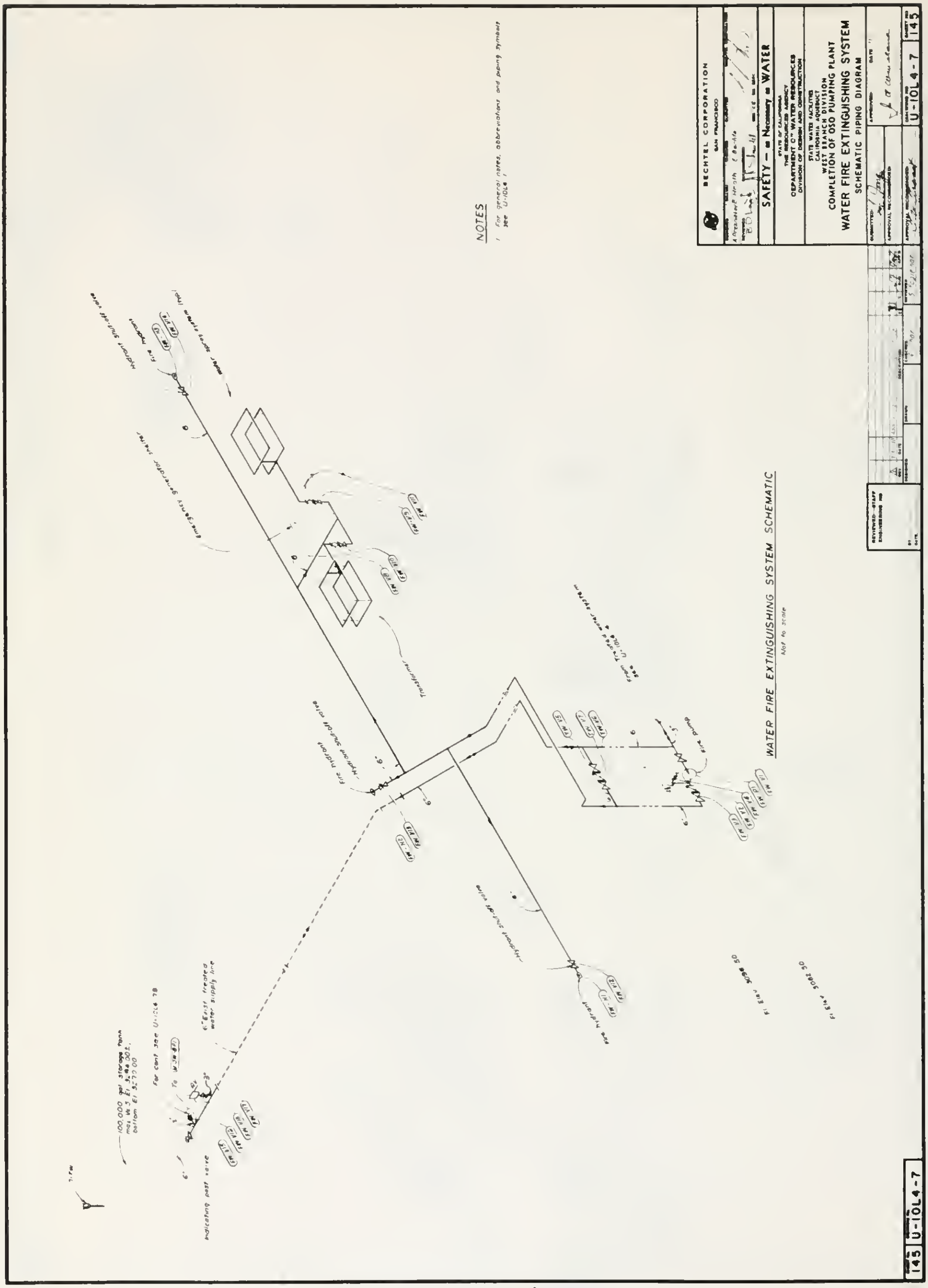

Figure 797. Water Fire-Extinguishing System

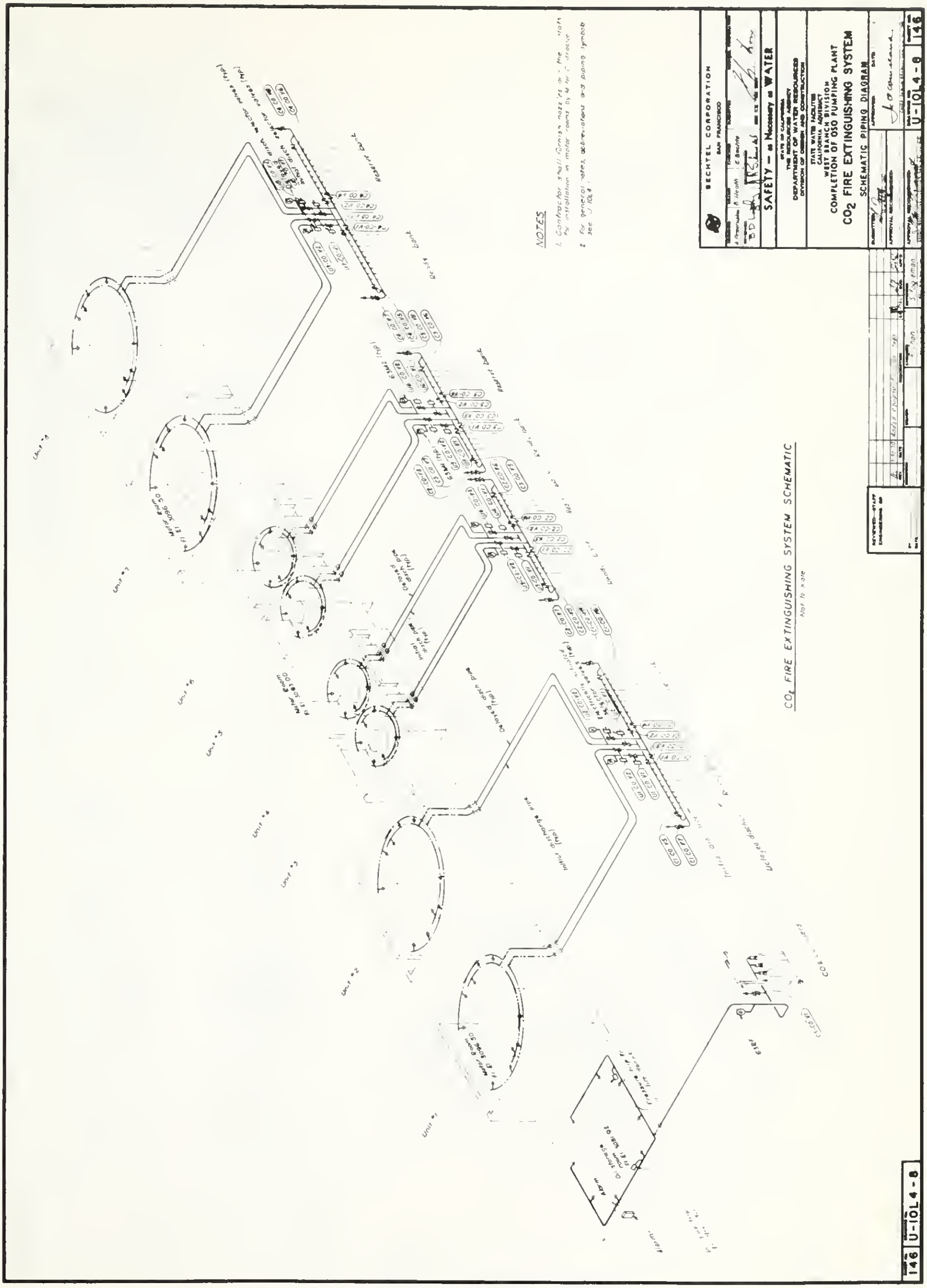

Figure 798. Carbon Dioxide Fire-Extinguishing System

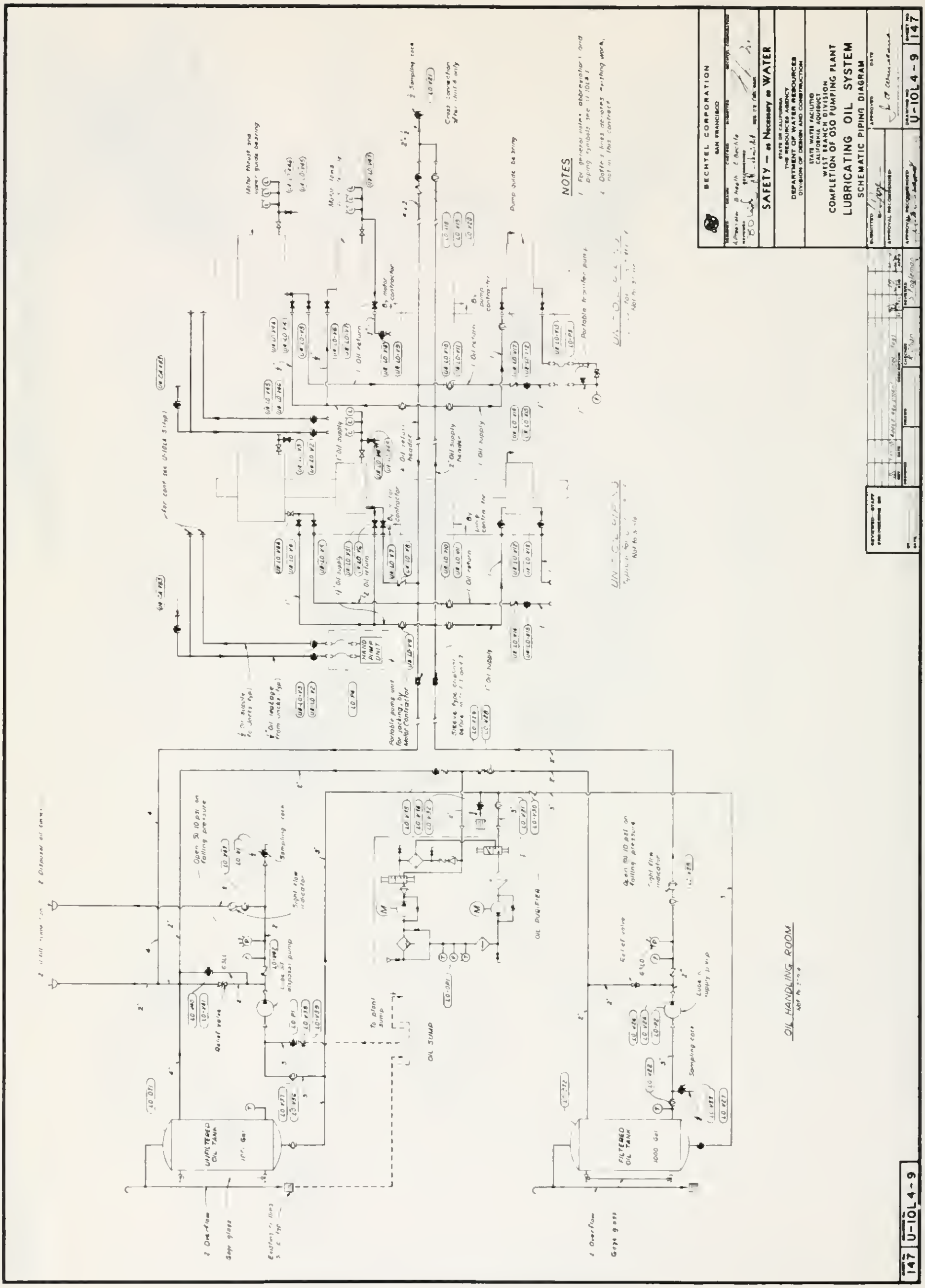

Figure 799. Lubricating Oil System

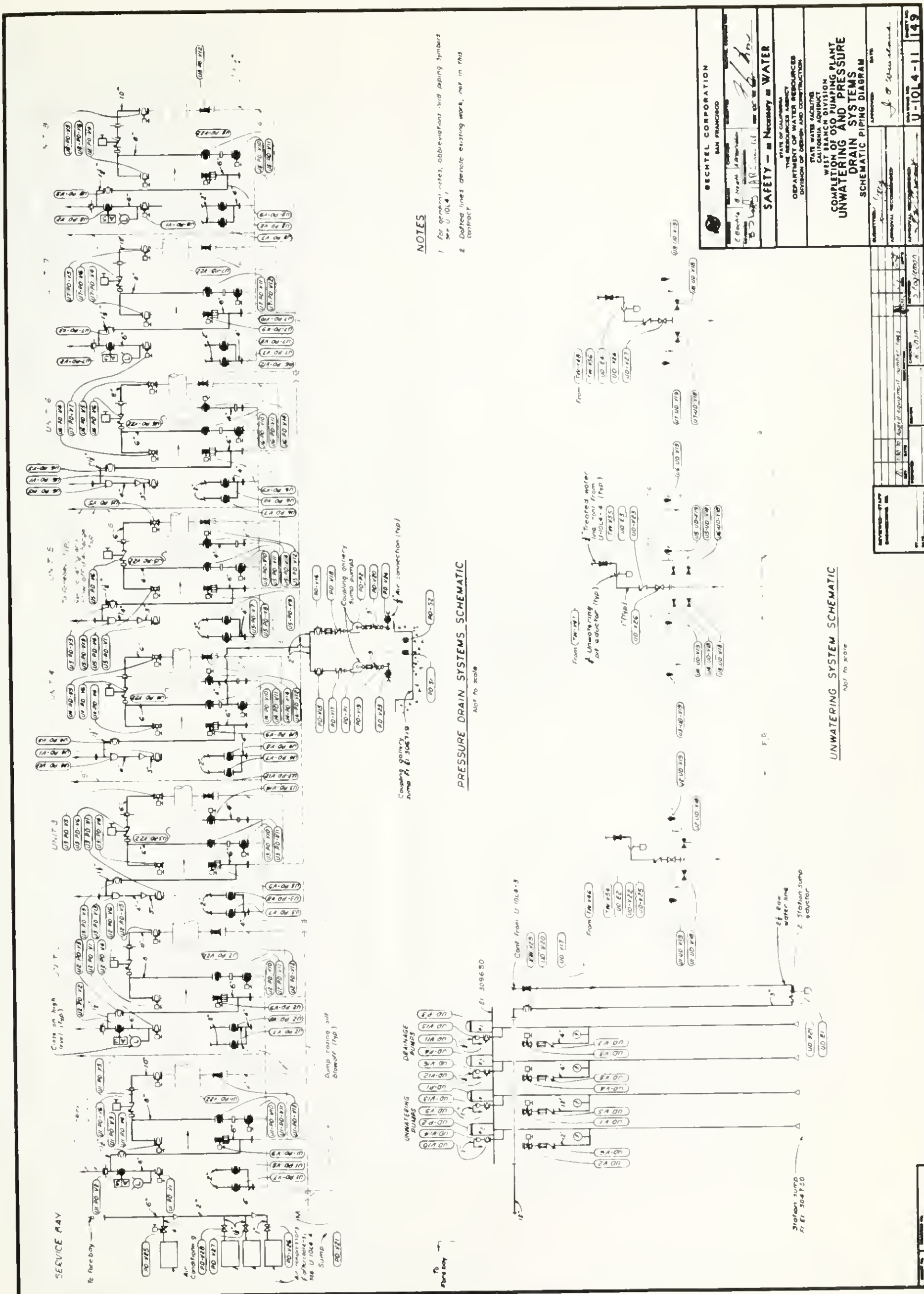

Figure 800. Dewatering and Pressure Drain Systems

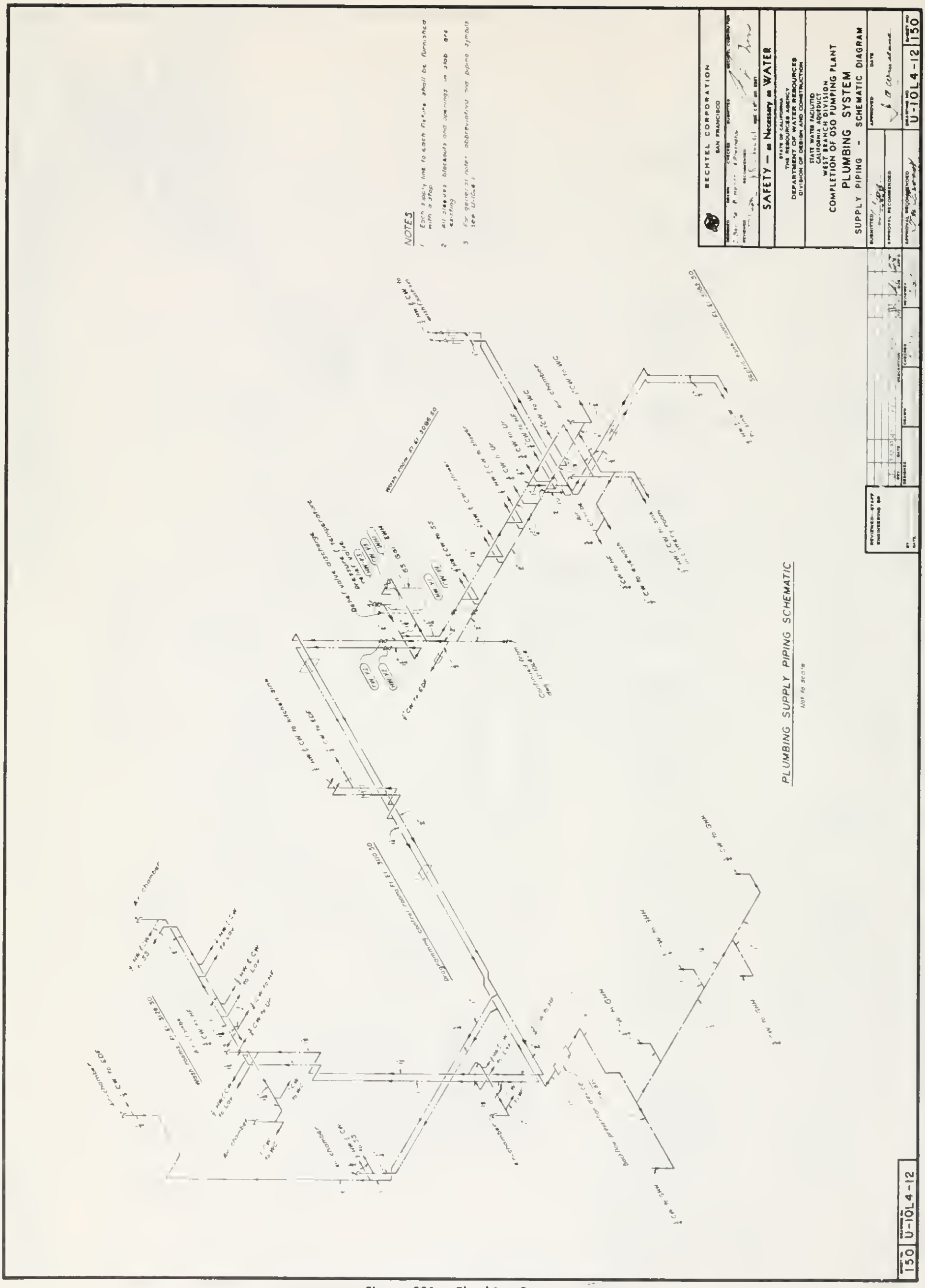

Figure 801. Plumbing System

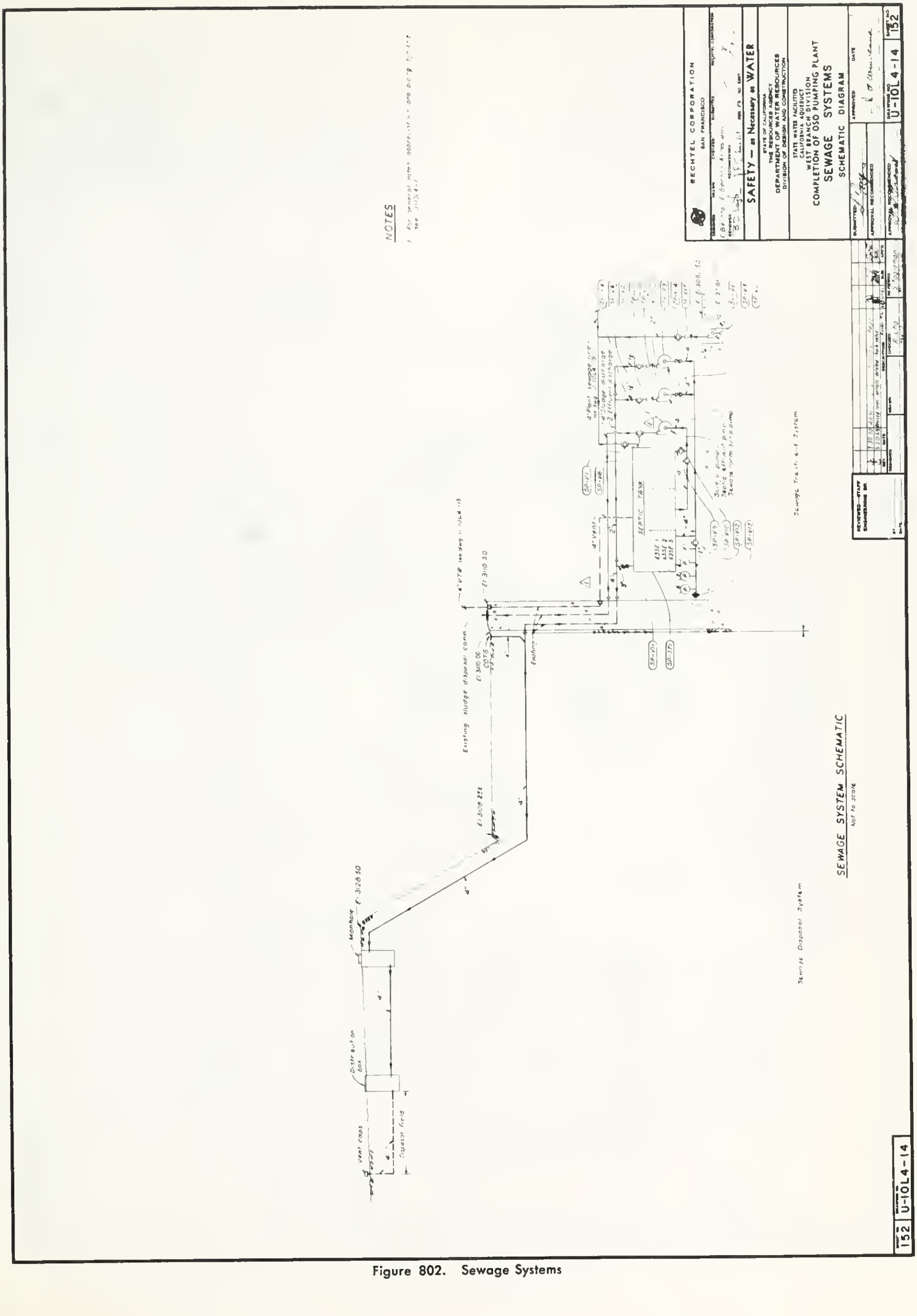

Figure 802. Sewage Systems

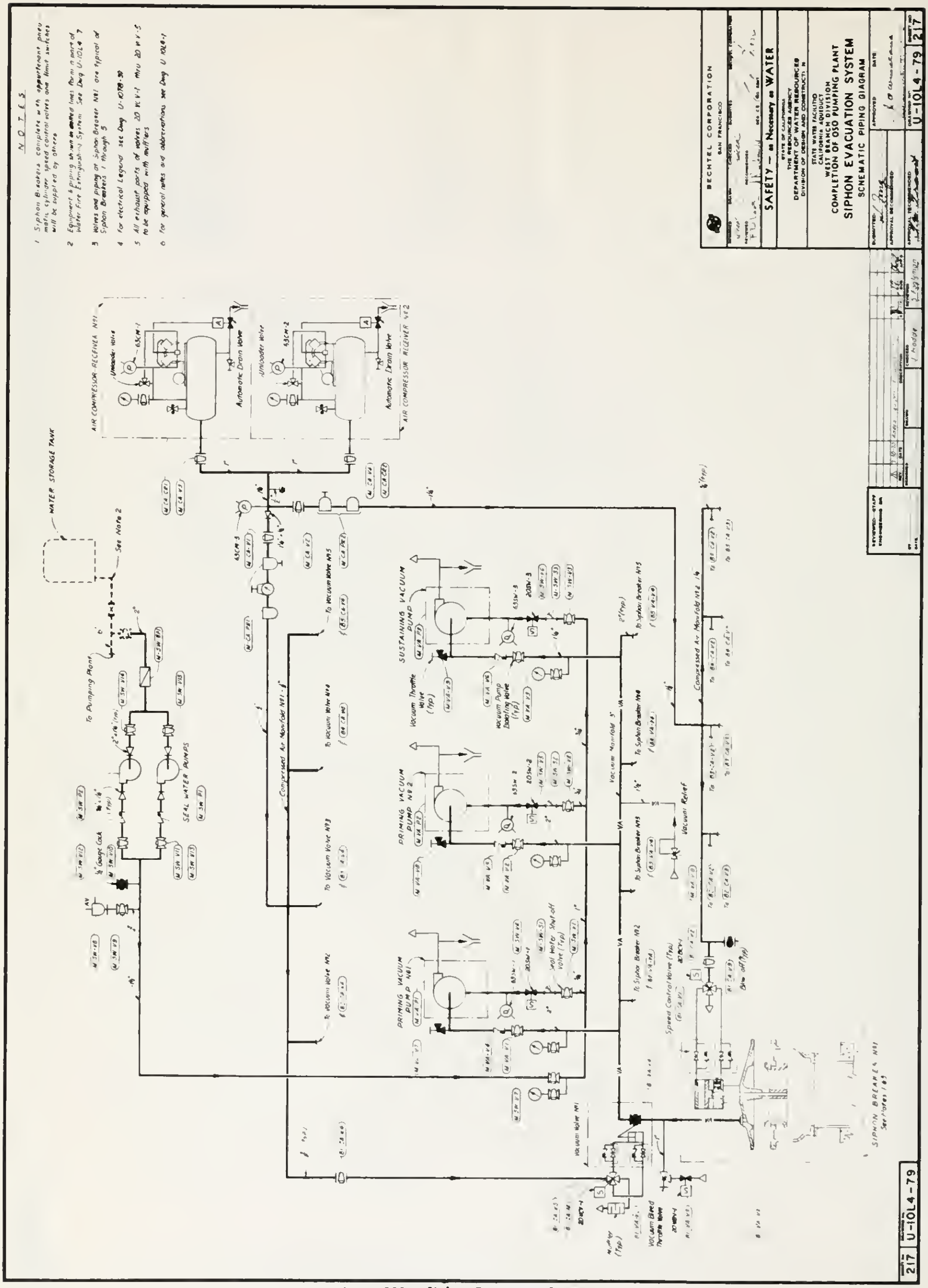

Figure 803. Siphon Evacuation System

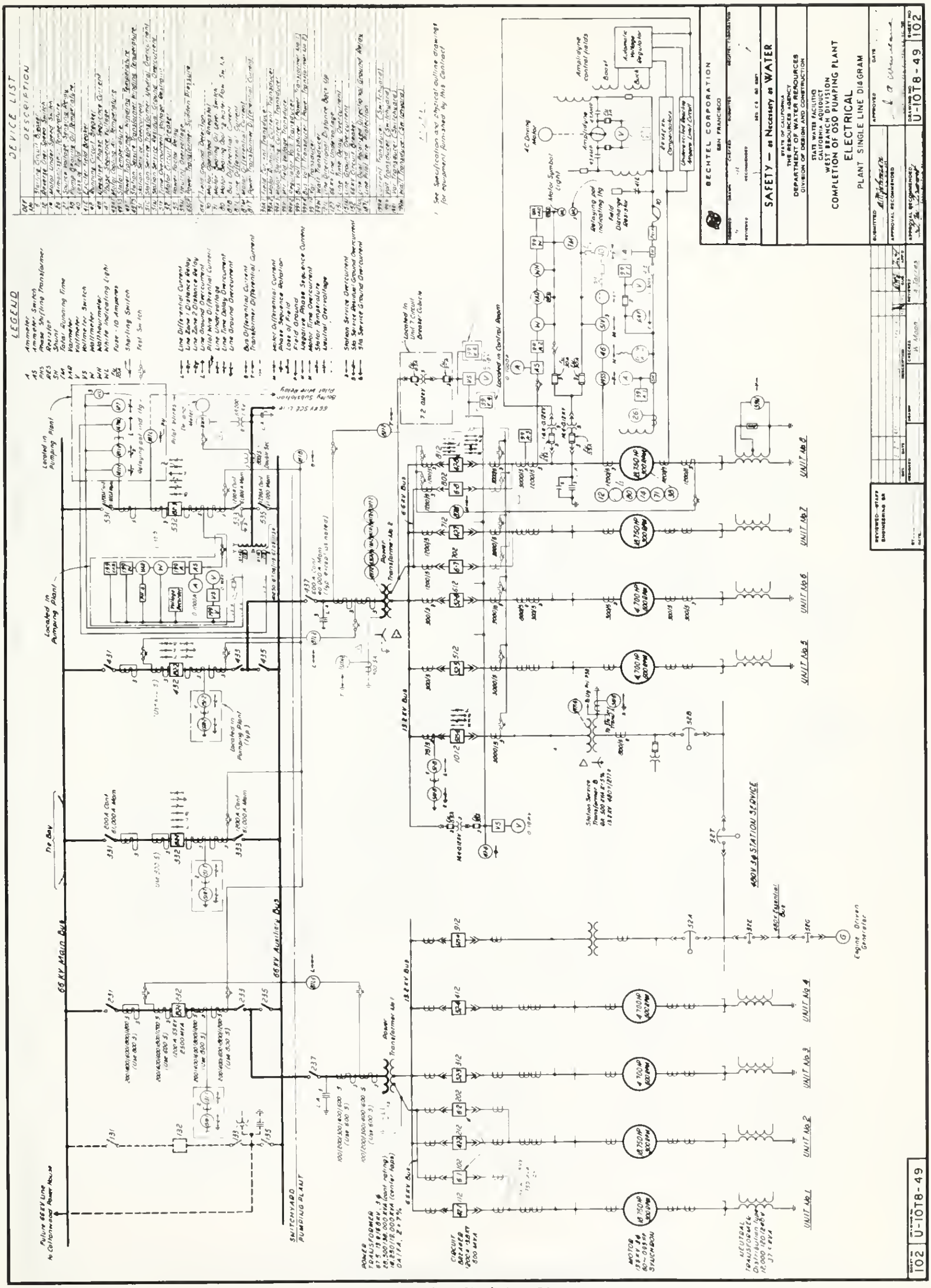

Figure 804. Plant Single-Line Diagram

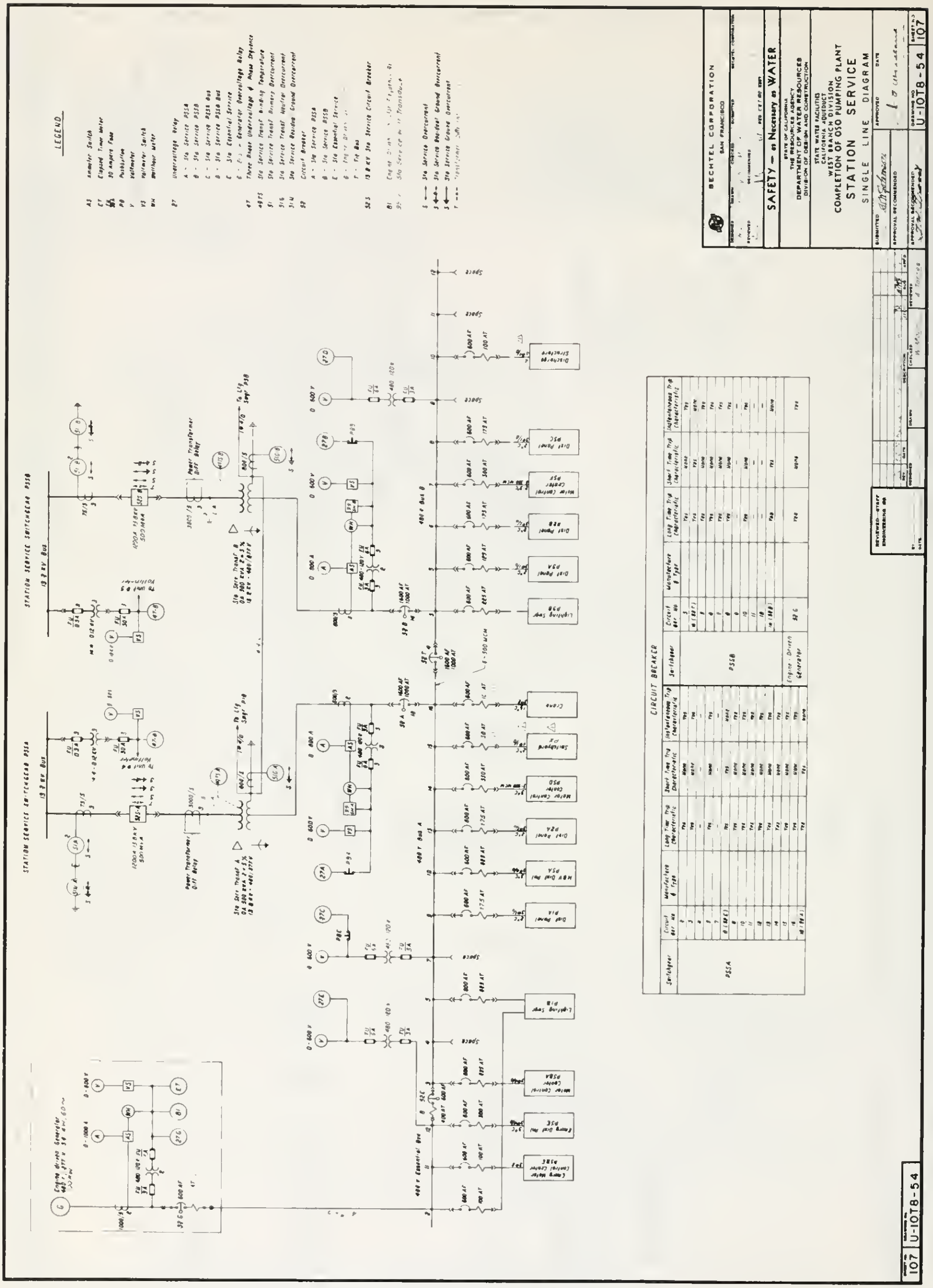

Figure 805. Station Service Single-Line Diagram

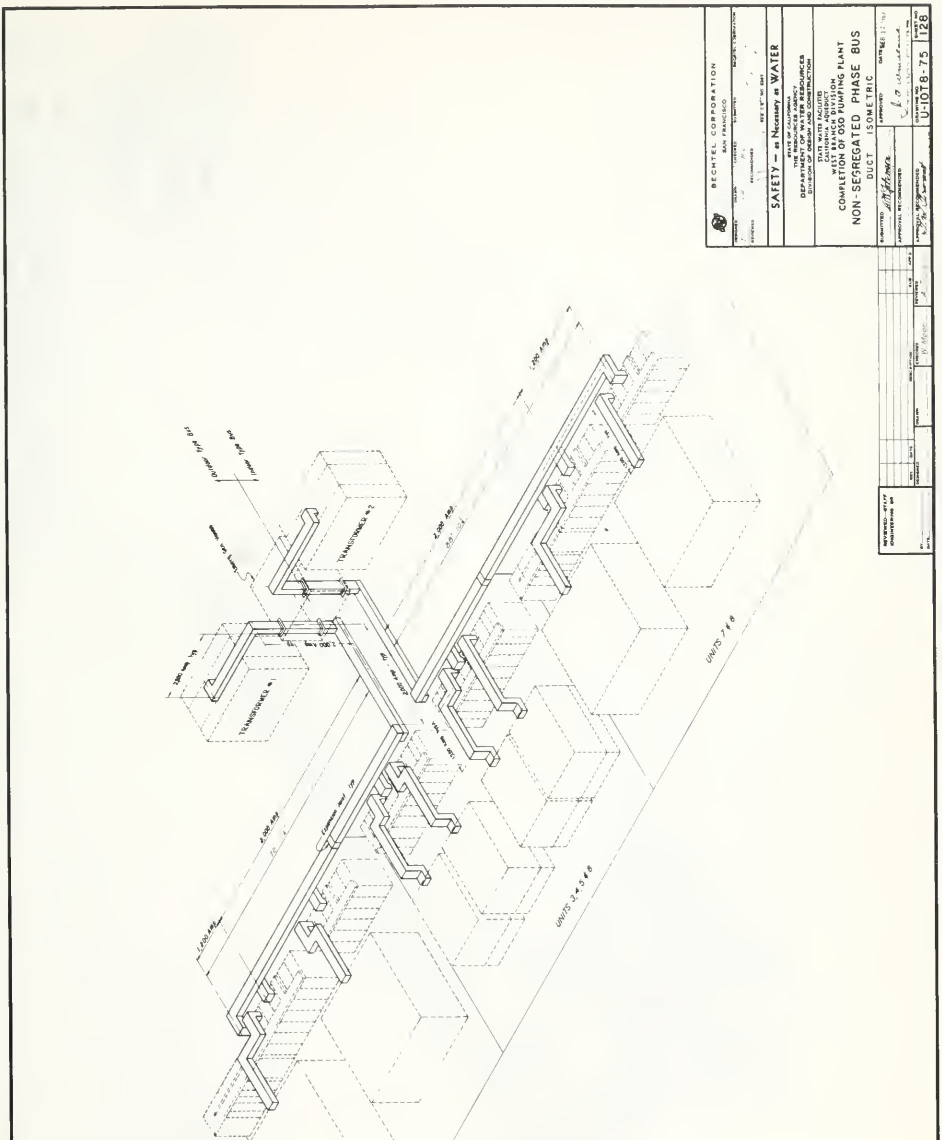

Figure 806. Nonsegregated-Phase Bus

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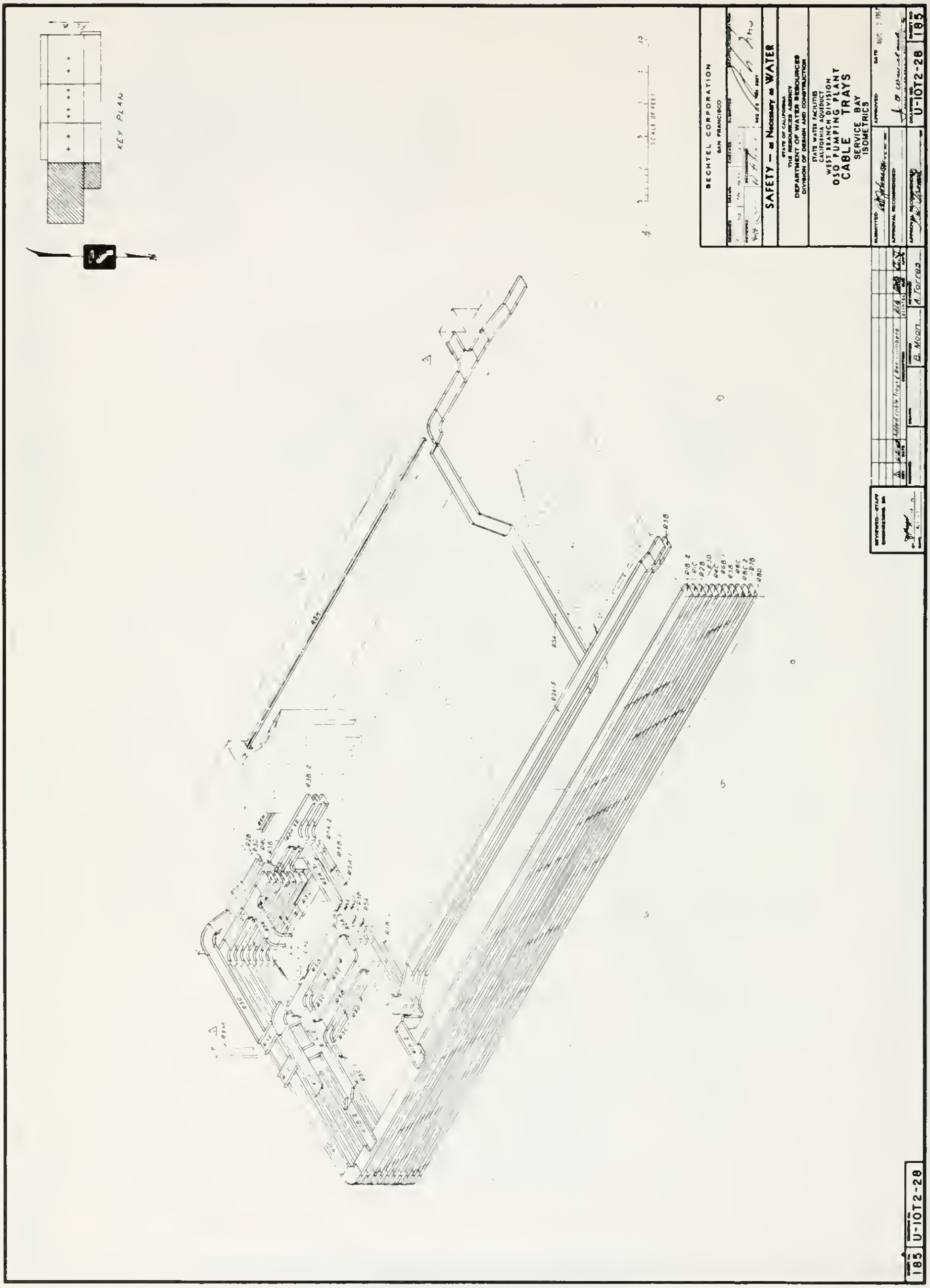

Figure 807. Cable Trays

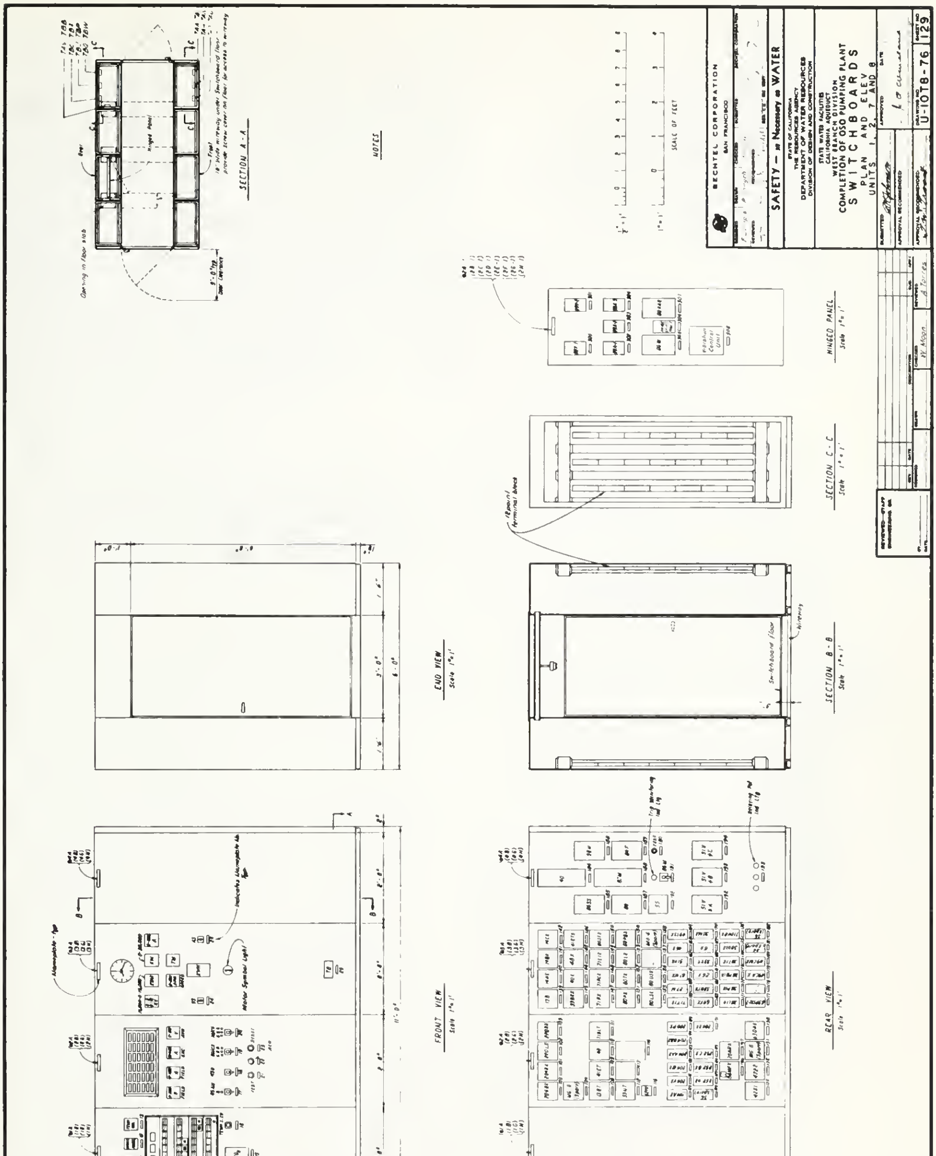

Figure 808. Switchboords

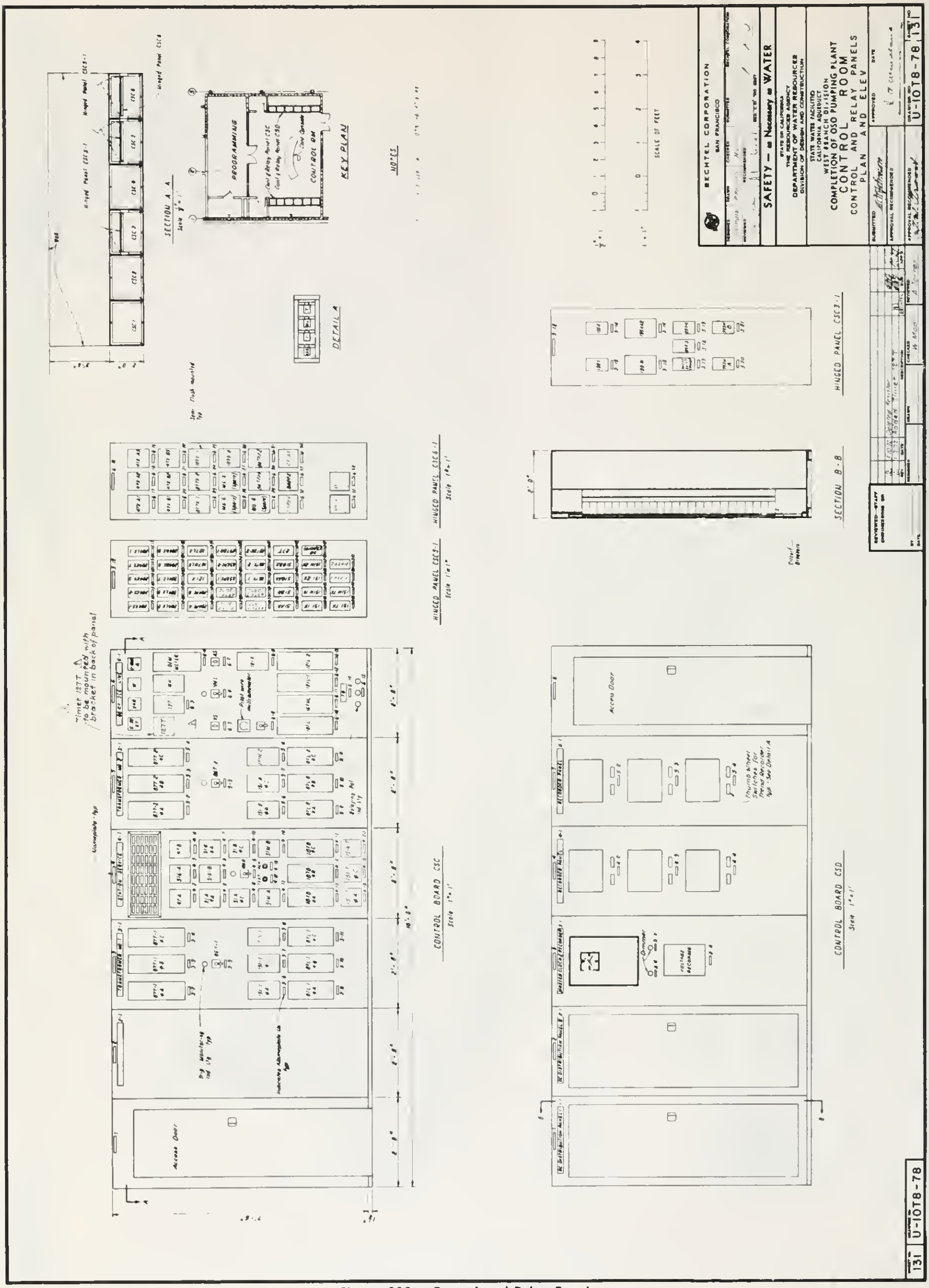

Figure 809. Control and Relay Panels

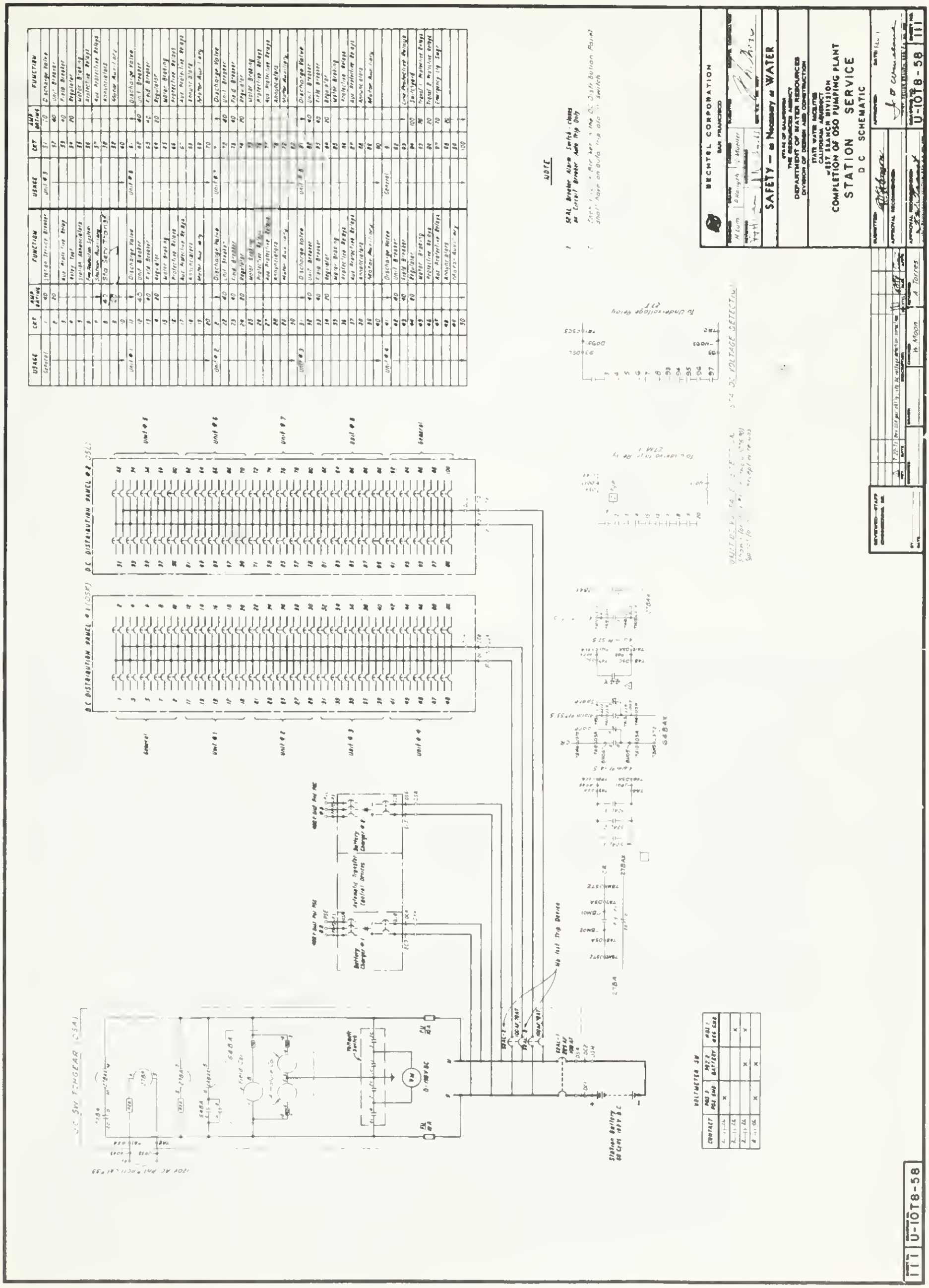

Figure 810. 125-Volt Direct-Current Schematic

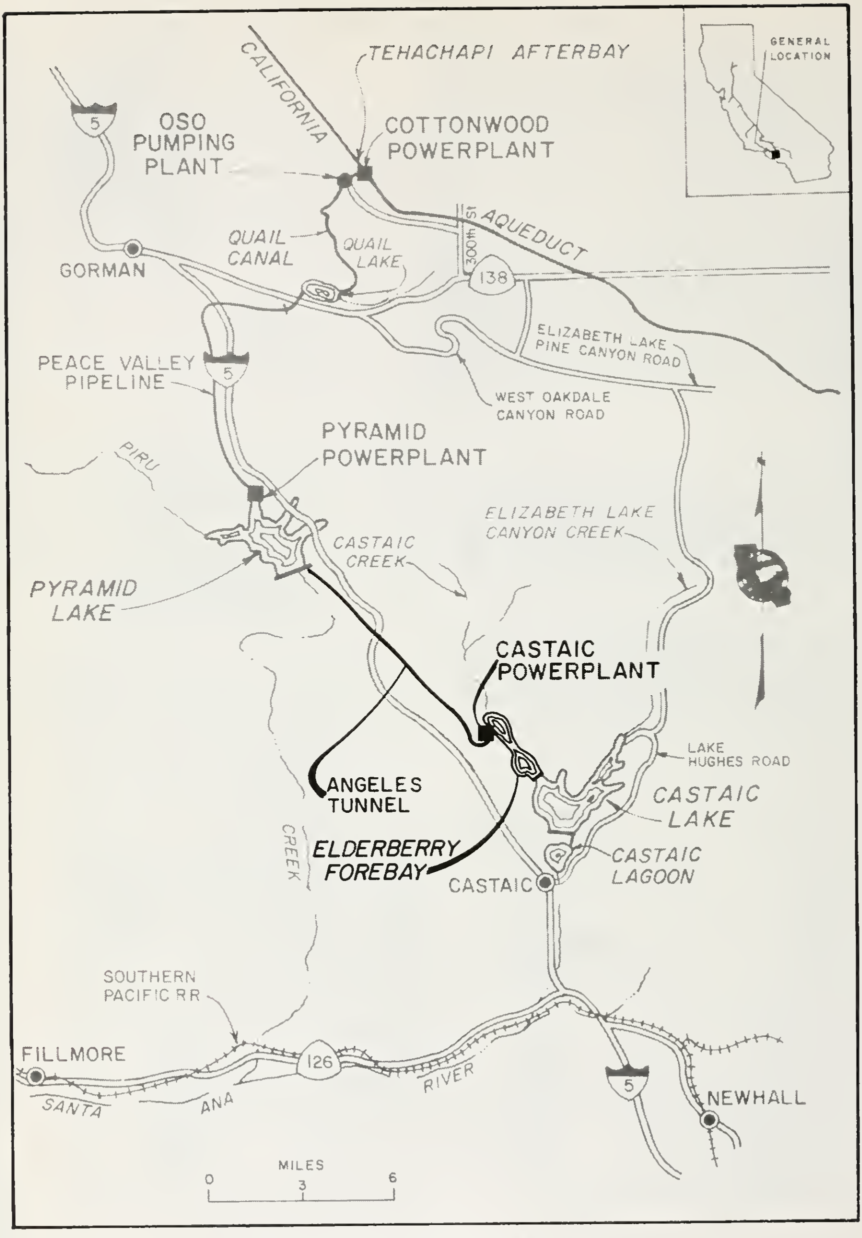

Figure 811. Location Map—Castaic Power Development

CHAPTER XVII. CASTAIC POWER DEVELOPMENT

General

Introduction

The 1,250-megawatt (MW) Castaic pumped-storage development was designed, constructed, and is being operated in accordance with the "Contract for Cooperative Development, West Branch, California Aqueduct" between the Department of Water Resources (Department) and Department of Water and Power of the City of Los Angeles (City) (Figure 811). It is located approximately 40 miles northwest of Los Angeles between Pyramid Lake and Castaic Lake. The originally proposed facilities were to be a state-only development of 214 MW for power recovery following the lift over the Tehachapi Mountains. The cooperative agreement between the Department and the City resulted in enlargement of the generation capacity and addition of a pumpback capability for larger peaking capacity. This was done on the concept that the Department would receive the same benefits as if a 214-MW conventional plant had been built, with the Department and the City sharing equally in the remaining benefits.

The major components of these power facilities are the Angeles Tunnel intake and emergency gate; the 30-foot-diameter, 37,775-foot-long, Angeles Tunnel; the Angeles Tunnel surge chamber; the 1,200-MW Castaic Powerplant; the 50-MW Unit 7 Powerplant; and Elderberry Forebay (Figures 812, 813, and 814). The powerplants, penstocks, and forebay were constructed by the City. All remaining components were constructed by the Department. Related features are Pyramid Lake which is utilized as the upper storage reservoir and Elderberry Forebay (formerly Castaic Forebay) which serves as the pumping forebay during pumpback operation. A 1,078-foot static head is available when a normal generation cycle begins, with Pyramid Lake at elevation 2,578 feet and Elderberry Forebay at elevation 1,500 feet. This chapter will treat these major features with emphasis on the features constructed by the Department. See Volume III of this bulletin for information on Pyramid and Castaic Dams. Pyramid power development is discussed in Chapter XVIII of this volume.

Figure 812. Aerial View—Castaic Powerplant

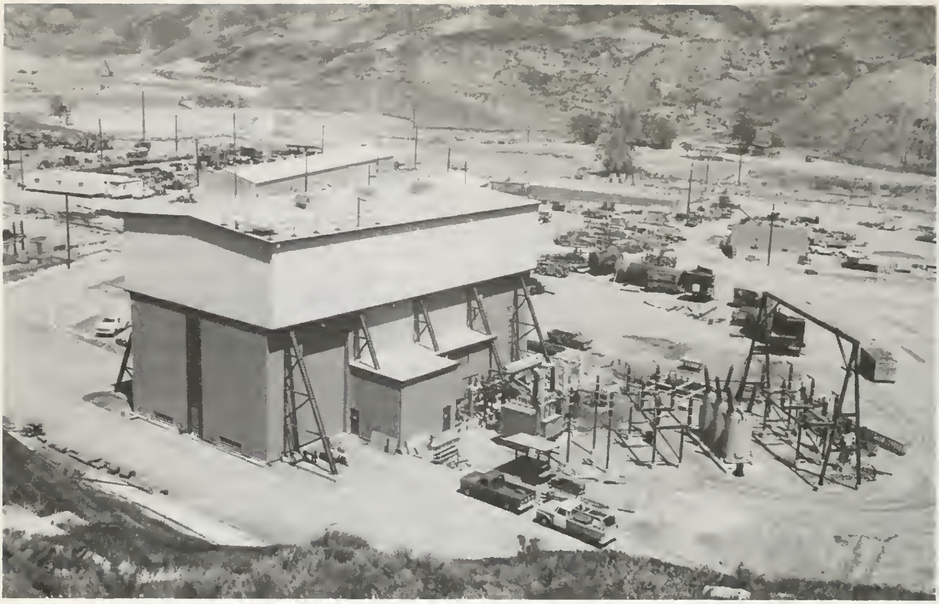

Figure 813. Aerial View—Unit 7 Powerplant

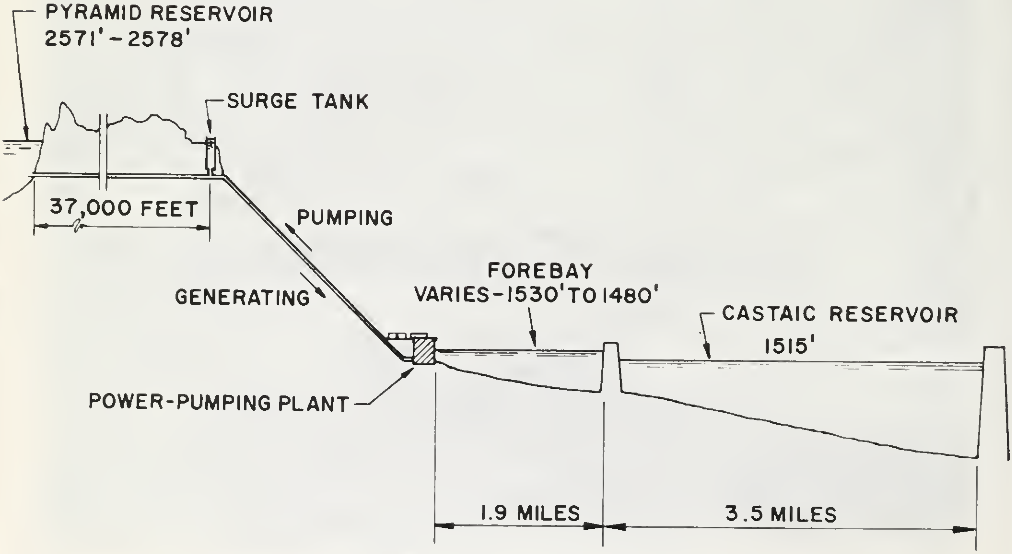

Figure 814. Castaic Power Development

Castaic Powerplant

Castaic Powerplant will ultimately contain six 200-MW, reversible, pump-turbine/motor-generator units spaced 65 feet on centers. Two 200-MW units are presently installed (1974), and the remaining units will be installed at one-year intervals beginning with Unit No. 3 in 1975.

The main powerplant structure is 500 feet long, 100 feet wide, and 150 feet high. A 100-foot by 100-foot service bay is located at the east end of the structure. The powerhouse (Figure 815) is serviced by two 375-ton-capacity bridge cranes with 25-ton auxiliary hooks.

Pump-Turbines

Equipment installed at Castaic Powerplant includes six 257-rpm reversible pump-turbines manufactured by Hitachi, Ltd., of Japan. All pump-turbines are vertical-shaft, single-stage, centrifugal type. Maximum net generating head is approximately 930 feet, and the maximum total pumping head is approximately 1,130 feet. Pump motors are rated at 350,000 horsepower each.

Under normal range of static head, the six generating units will be capable of generating 1,200 MW with a flow of 17,000 cubic feet per second (cfs). Pumping capability at normal static head will range from 2,200 cfs with one unit operating to approximately 12,000 cfs with six units pumping.

Motor-Generators

Motor-generators are vertical-shaft, synchronous, modified umbrella-type machines with two guide bearings, high-pressure oil-lift thrust bearings, and a thyristor-type static excitation system. Any one unit can be started in the pumping mode by the synchronous method using Unit 7 (50-MW impulse turbine). In addition, one of the pump-turbines can be used as a generator for back-to-back starting of another pump-turbine unit as a pump.

Unit 7 Powerplant

Unit 7 Powerplant is located about 500 feet from the main Castaic Powerplant. It contains one 50-MW vertical-shaft generator driven by a six-nozzle impulse turbine operating at 225 rpm.

This plant was placed in operation on February 12, 1972 so the Department could meet its contractual obligation for delivering water to water users served from Castaic Lake during initial water deliveries prior to initial operation of Castaic Powerplant, which began in July 1973. In accordance with the West Branch Cooperative Development Agreement, Unit 7 was designed for a minimum flow of 500 cfs.

Switchyard

The switchyard is located immediately behind Castaic Powerplant. Because of restricted space and the necessity of isolating a common bus for pump starting

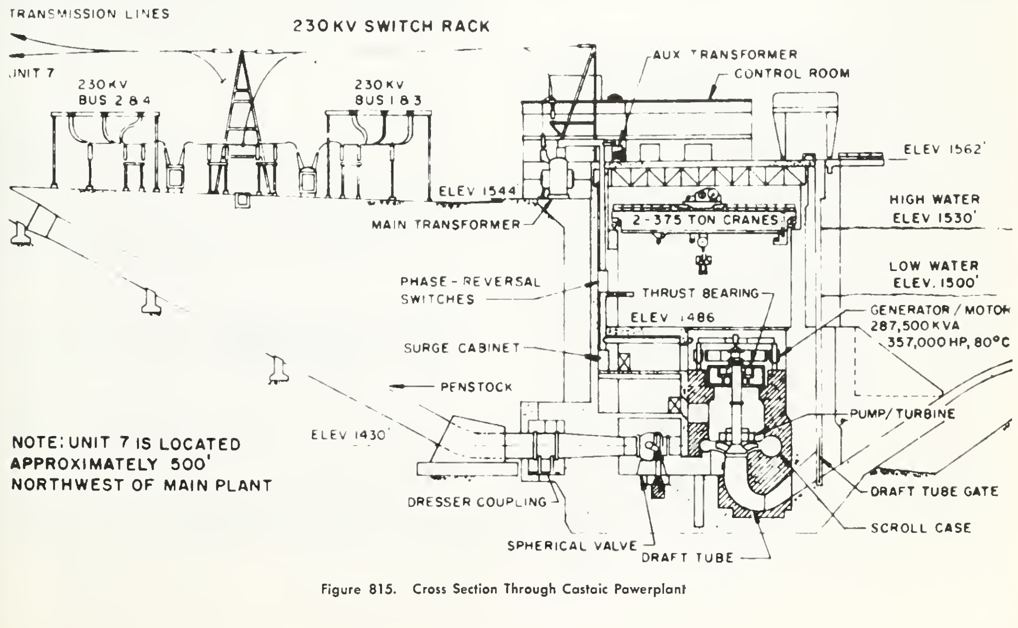

Figure 815. Cross Section Through Castaic Powerplant

connections, a double bus-double breaker arrangement was provided. Each bus is sectionalized with a circuit breaker to prevent the possibility of rejecting total plant pumping load during the pump starting process.

Elderberry Forebay

The pumping forebay is formed by the Elderberry Forebay Dam. It retains water for pumping when the water surface in Castaic Lake drops below the minimum level required for pumping. The Forebay is 1.9 miles long and provides live storage of 18,000 acre-feet.

Geology

Areal Geology

The component sites lie within the Ridge Basin, part of the Transverse Range geologic province. The northern boundary of the Ridge Basin is the San Andreas fault, the western boundary is the southwest-trending San Gabriel fault, and the eastern boundary is a complex of granitic and metamorphic rock overlain by nonmarine sediments on the south. The prominent topographic features of the Ridge Basin are dip slopes with sharp-crested ridges that are steeply tilted to the west and northwest.

The Angeles Tunnel penetrates through sedimentary rock of the Castaic formation and the Ridge Basin group. The foundation for Castaic Powerplant is the Castaic formation. Both geologic units are very similar, consisting of a uniform interbedded sequence of northwest-dipping sandstones and siltstones with a few shaley members. Alluvial deposits overlay these older units.

Angeles Tunnel

Because of the similarity between the Ridge Basin and Castaic formation, the Angeles Tunnel was mapped by rock types. The percent of each rock type mapped was sandstone 25%, sandstone-siltstone 27%, siltstone 35%, shale 5%, argillite 5%, and fault gouge 3%.

In underground exposures, the sandstones are light gray to tan, fresh, soft to friable to moderately hard, and fine to medium grained. The sandstones range from very thickly bedded to thinly bedded. The sandstones contained relatively open and continuous jointing at high angles and at 60 degrees to the strike of the beds. The sandstones exposed during tunneling were usually wet and proved to be troublesome because joint blocks in the roof tended to produce a moderate to large overbreak.

The sandstone-siltstone rocks contain mixtures of sand and silt with sand grains predominant. The sandstone-siltstone rocks in the Tunnel are fresh, dark brown-gray to gray, with a moderate hardness and generally little fractured.

The siltstone unit at depth is dark gray to gray, fresh, fine grained with moderate to low hardness. The siltstones are thickly bedded or occur as thin interbeds in thick sequences. The thick-bedded siltstone is generally little fractured to massive. The shales occur as dark gray scattered interbeds up to 3 inches thick, usually in the Castaic formation. The argillite is dark gray, fresh, moderately hard, brittle, and laminated to thin bedded, containing zones of minor warping and close fracturing parallel to the Tunnel.

The most common occurrence of fault gouge is in internally sheared beds. Bedding plane faults, usually thrust faults, are the prominent structural features exposed by the Tunnel. Other faulting crosses the Tunnel from north to south with gouge zones up to 1 foot thick.

In the Tunnel, the predominant jointing is perpendicular to the bedding planes, producing localized sheeted zones or single-rock fractures.

Geologic Exploration. Exploration consisted of geologic mapping, core drilling, and rock and water testing. An exploratory adit was driven at Osito Canyon, and electric logs were taken of selected drill holes.

Instrumentation. Special survey hubs were installed at selected areas in the Angeles Tunnel. Elevations of the hubs were recorded to determine amount and rate of movement of the rock in these areas. Rosette-type, photoelastic, strain gauges were installed on invert steel ribs in selected problem areas to show distortion and direction of stress in the support members. Interstate Highway 5, which is located near the tunnel alignment, was under construction during tunnel construction. Blasting for Interstate 5 excavation was investigated by means of seismograph readings of the blasting. The highway blasting did not cause damage to the Tunnel or the steel support system.

Surge Tank

The foundation for the surge tank is the Castaic formation. The sedimentary rock is predominantly sandstones, with interbedded siltstones and minor shales. The rocks typically showed little fracture. A ½- to 8-foot-thick fault zone passes through the junction structure, connecting shaft, and the basal position of the surge chamber. No construction difficulties were encountered other than minor slipouts.

Geologic Exploration. Rotary core drilling, geophysical surveying, and geologic mapping were used in exploring the surge chamber foundation.

Instrumentation. Instrumentation in the surge chamber included strain gauges applied to the ring beam support system and measurement of elevation changes in ring beams 1 and 52.

A total of 35 gauges (SR-4 series) was attached to the ring beams in groups of three: one gauge was cemented to the flange, another to the web, and a third to a steel-plate "dummy" for temperature compensation.

Castaic Powerplant and Penstock

The bedrock at the site is Castaic formation consisting of predominantly siltstone with sandy siltstone and silty shale. It is thinly laminated to thinly bedded with a distinctive joint pattern. The dominant structural features are uniformly inclined strata dipping west 5 to 20 degrees. Soft sediment deformation has resulted in folding and slumping of the beds. Shear zones and faulting were mapped within the excavation area. Numerous landslides have been mapped in the area of Castaic Creek and on the west slopes.

Field investigations indicated that there were no faults or landslides which should affect the penstocks or the Unit 7 Powerplant.

Geologic Exploration. Rotary core drilling, auger drilling, and trenching were employed in selecting the sites.

Areal Seismicity. The tunnel and plant are located in a seismically active area. The San Andreas fault zone lies 8 to 10 miles northwest, and the Clearwater fault lies about 3 miles north. The San Gabriel fault is about 1½ to 2½ miles south and west. These facilities will undoubtedly experience seismic shaking several times during their service period.

Design of Angeles Tunnel and Appurtenances

Intake works

The intake works consist of two main features: the intake structure with trashracks, and the tunnel gate facility (Figure 816).

The intake structure located at the north portal of the Angeles Tunnel is a large, gravity, reinforced-concrete structure anchored to the rock foundation. This anchorage increases the factor of safety against sliding and seismic ground shaking. The intake provides a means for water withdrawal from and discharge into Pyramid Lake for the pumping-generating Castaic Powerplant.

The intake draws water from Pyramid Lake down to elevation 2,345 feet, which is 10 feet above the projected silting elevation. Stainless-steel trashracks with 6-inch openings cap the intake and are located 230 feet below the normal lake level of 2,578 feet.

The intake structure was designed to carry flows of 18,400 cfs in the generating mode. The design flow for the pumping mode is 17,300 cfs. The maximum flow rate of 32,000 cfs was established by considering a severe emergency condition in the downstream conveyance which contemplated complete severance of the Tunnel.

The tunnel gate facility is located some 900 feet downstream from the intake structure. It consists of a gate transition structure in the Tunnel; a gate shaft extending 303 feet up to elevation 2,592 feet; a gate maintenance chamber; a large hydraulic cylinder; and operating mechanism for gate control, gate stems, and the emergency gate. Appurtenant facilities include an operating area at elevation 2,643 feet, a control building, reservoir gauging station, and an air shaft. The air shaft also serves as a resurge relief from the Tunnel in case of inadvertent closure of the emergency gate.

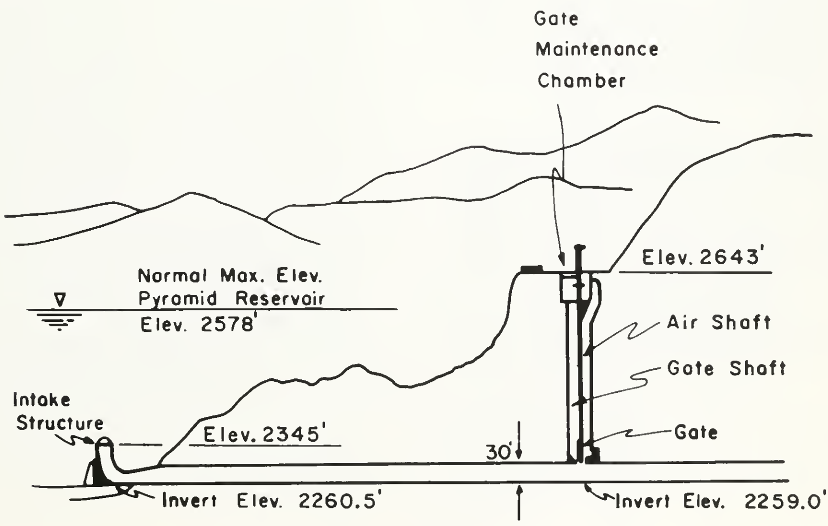

Figure 816. Profile, Intake Structure, and Tunnel Gate Facility

Hydraulic Design. The intake facilities, combined with the Tunnel, the surge chamber, and the penstocks, deliver flow to and from Castaic Powerplant. Following are design flow rates for the various conditions listed:

	Reservoir elevation (feet)	Tail bay elevation (feet)	Flow (cfs)
Generating mode			
275,000 horsepower 6 units	2,571/2,578	1,500/1,530	16,400/17,640
275,000 horsepower 6 units	2,561	1,530	18,000
Maximum flow	2,571/2,578	--	18,400
Pumping mode			
Maximum flow	2,370	1,530	17,300
Normal flow	2,571/2,578	--	12,000

Intake Structure. The intake structure is a multiple-compartmented structure (four 22-foot by 22-foot horizontal openings) which bends through 90 degrees for vertical discharge and withdrawal in the reservoir, and forms a transition to the 30-foot-diameter Angeles Tunnel (Figure 817). The hydraulic principles employed are those used in designing draft tubes and turbines. The structure was sized using these principles and was then verified with an air model to check the predicted performance. The intake configuration was modified during the model study by adding two additional vanes. These vanes eliminated a flow stall that had plagued the original configuration. The major objective of the study was to reduce high velocities in the pumping mode at the trashracks. Tunnel velocities are a maximum of approximately 24.5 feet per second during 17,300-cfs pump flows. Exiting flows from the final configuration are held to between 10% and 65% of this value, with a mean velocity value of 36%.

Tunnel Gate. The gate (Figure 818) is provided to isolate the reservoir from the Tunnel for maintenance and to serve as an emergency shutoff device in case of tunnel rupture or failure of features at Castaic Powerplant. The gate was not designed to control flow; flow control is provided at Castaic Powerplant. The gate is located in the center of a transition structure (30 feet high by 18 feet wide) approximately 130 feet in length (Figure 819). The upstream and downstream transitions are similar since generating and pumping flows are nearly equal. The gate slot is located in the center of the 20-foot-long rectangular section.

Hydraulic Design. The gate is designed to close under full emergency flow of 32,000 cfs. It is not designed to open under full reservoir head with the Tunnel dewatered. To open the gate under this condition (downstream tunnel dewatered), a 24-inch bypass valve system is provided which permits filling of the Tunnel in approximately 30 hours. When the head differential is approximately 20 feet, the gate can be opened. The gate is not to be closed against reverse flow when Castaic Powerplant is pumping. Controls are incorporated to shut down the pumps should the gate accidentally close.

Extensive model testing of the gate was conducted at the Water Science and Engineering Laboratory of the University of California at Davis. The primary purpose of the study was to observe gate behavior while closing under full flow and against full reservoir head. The study also observed the total load on the gate over the entire range of gate movement during closure, including fluctuations forced by hydraulic turbulence in the transition.

Structural Design. The gate is a flat-leaf coaster-type gate with two continuous roller trains on each side to distribute the hydraulic forces to the roller tracks (Figure 820). It is 25 feet wide by 32 feet high by 4 feet thick and was designed to withstand full reservoir head of 320 feet. The gate has a downstream skinplate and downstream seals and weighs in excess of 360,000 pounds.

The gate is held by a steel lifting stem with 14 removable sections. The total length of the stem is slightly over 318 feet and the weight in excess of 180,000 pounds.

The stem has a uniform cross section composed of two W21×142 A36 structural shapes welded together. Alignment of the stem and its mating surfaces is critical with regard to fabrication, installation, and maintenance.

The stem is joined and connected to the gate and the hydraulic piston rod with a stem coupling device. The hydraulic cylinder which operates the gate has a 5-inch-thick base plate supported on two large steel-plate girders that span the gate maintenance chamber and are anchored to the reinforced-concrete walls. The stroke of the 32-inch hydraulic piston required for gate closure is over 33 feet. Working pressure of the hydraulic system is 1,100 pounds per square inch (psi), and the time required to close the gate is slightly over 10 minutes. When not in use, the gate and stem sections are supported on structural dogging devices located in the maintenance chamber.

The hydraulic system is equipped with pumps, sumps, accumulators, flow control valves, and related equipment necessary for automatic gate closure. Intricate electrical circuits equipped with the necessary limit switches and supervisory control features are provided so that the gate can be remotely closed in an emergency, either from the area control center at Castaic Dam or from Castaic Powerplant. However, the gate must be opened on the site by manual controls located in the maintenance chamber.

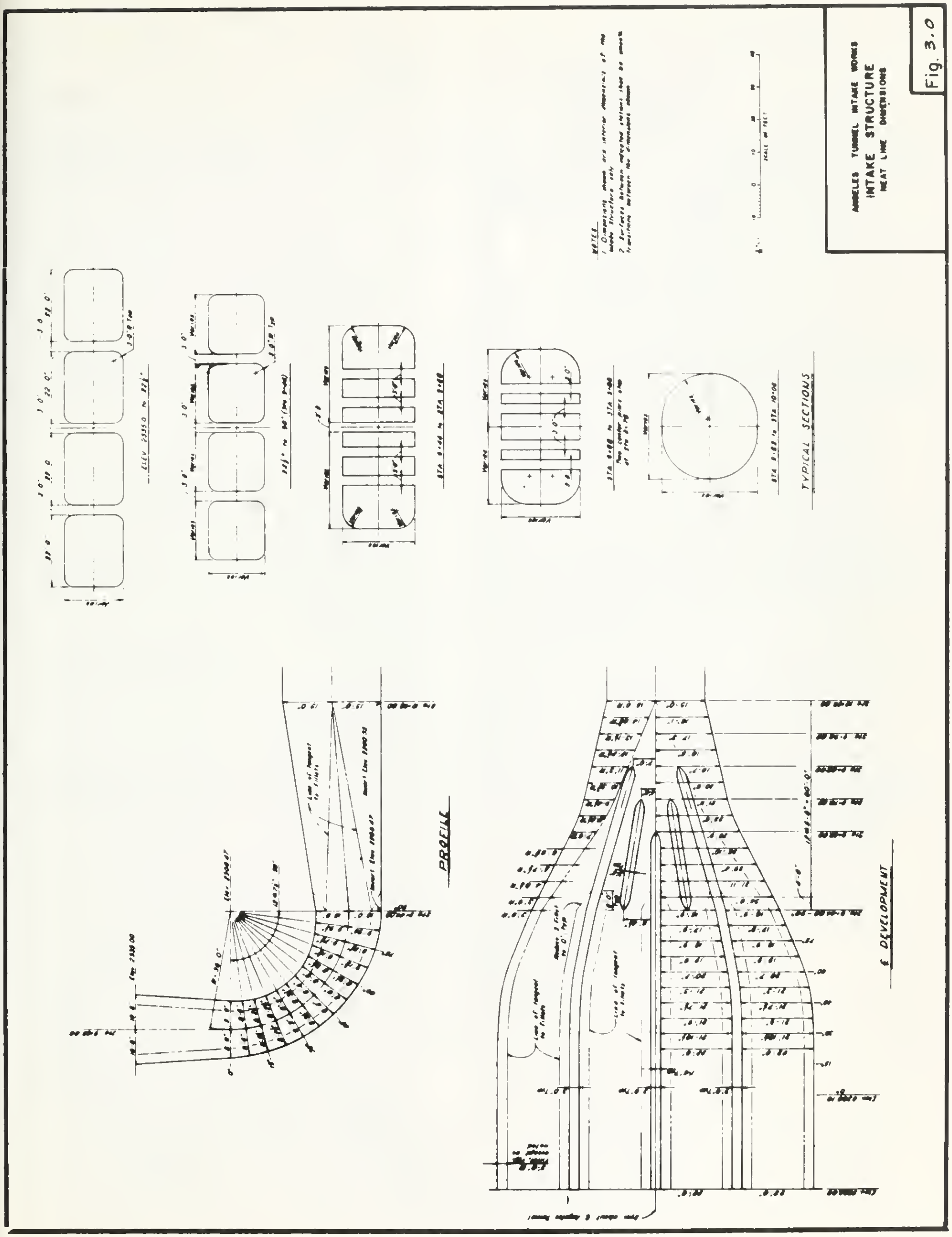

Figure 817. Angeles Tunnel Intake Structure

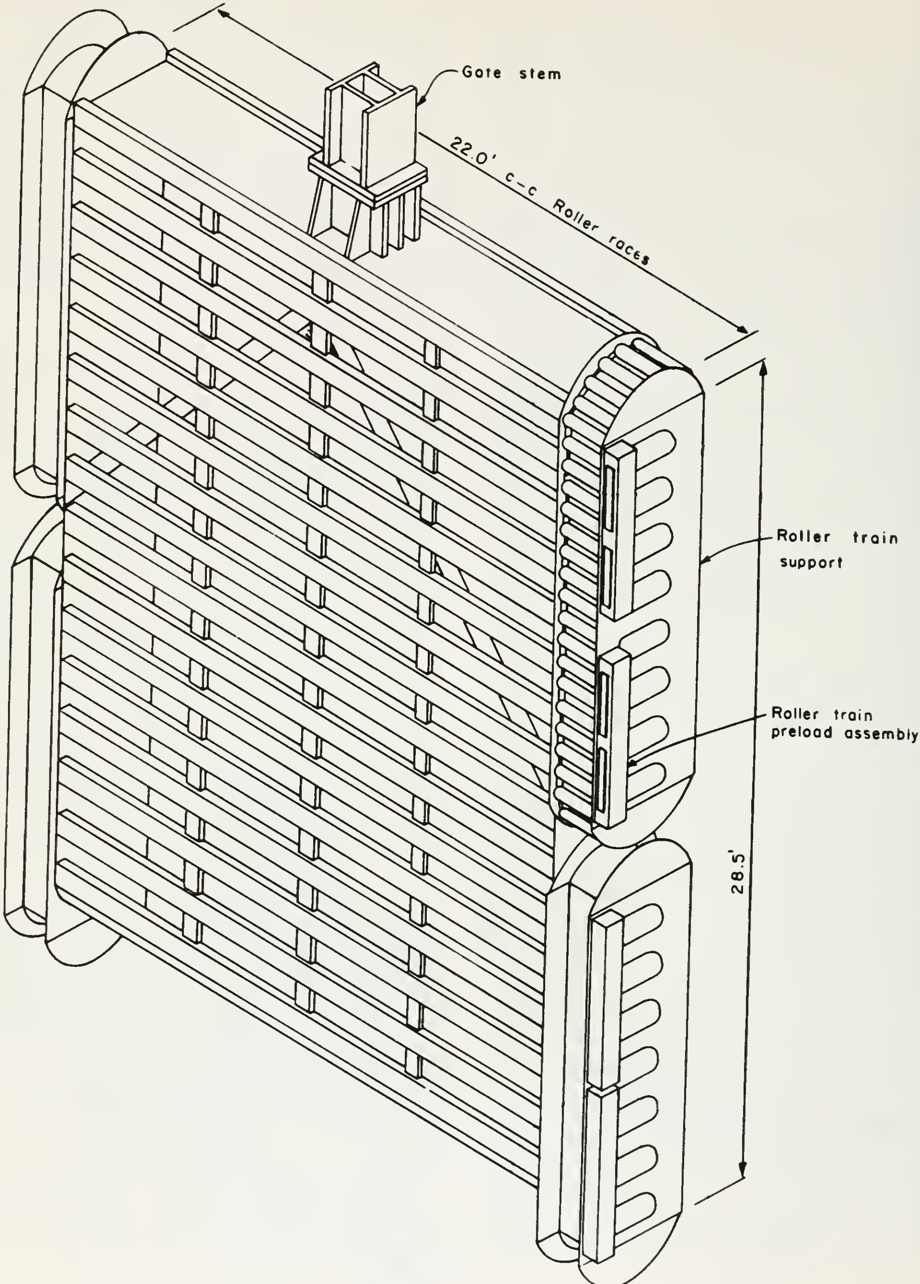

Figure 818. Angeles Tunnel Gate

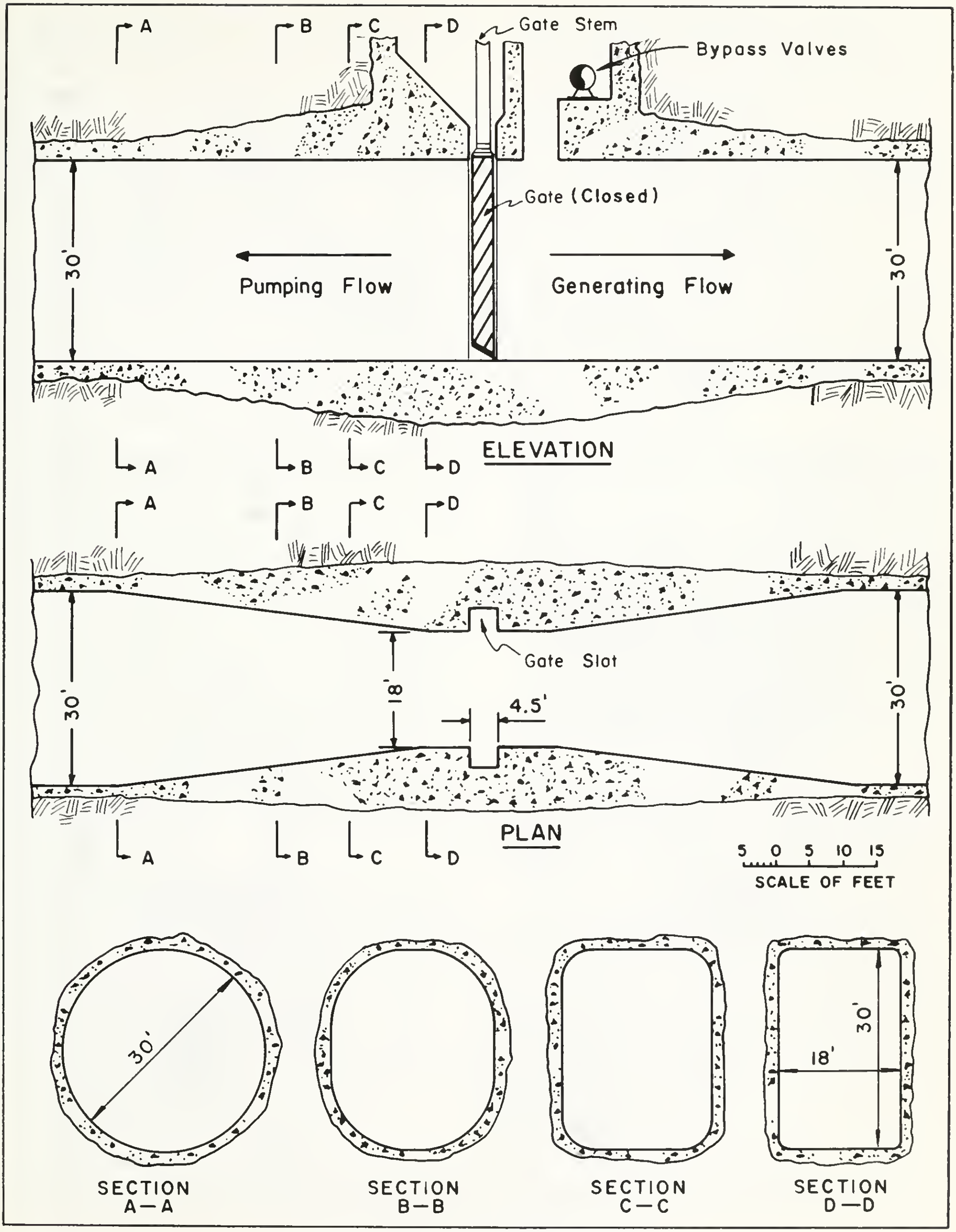

Figure 819. General Layout of Gate Transition Structure

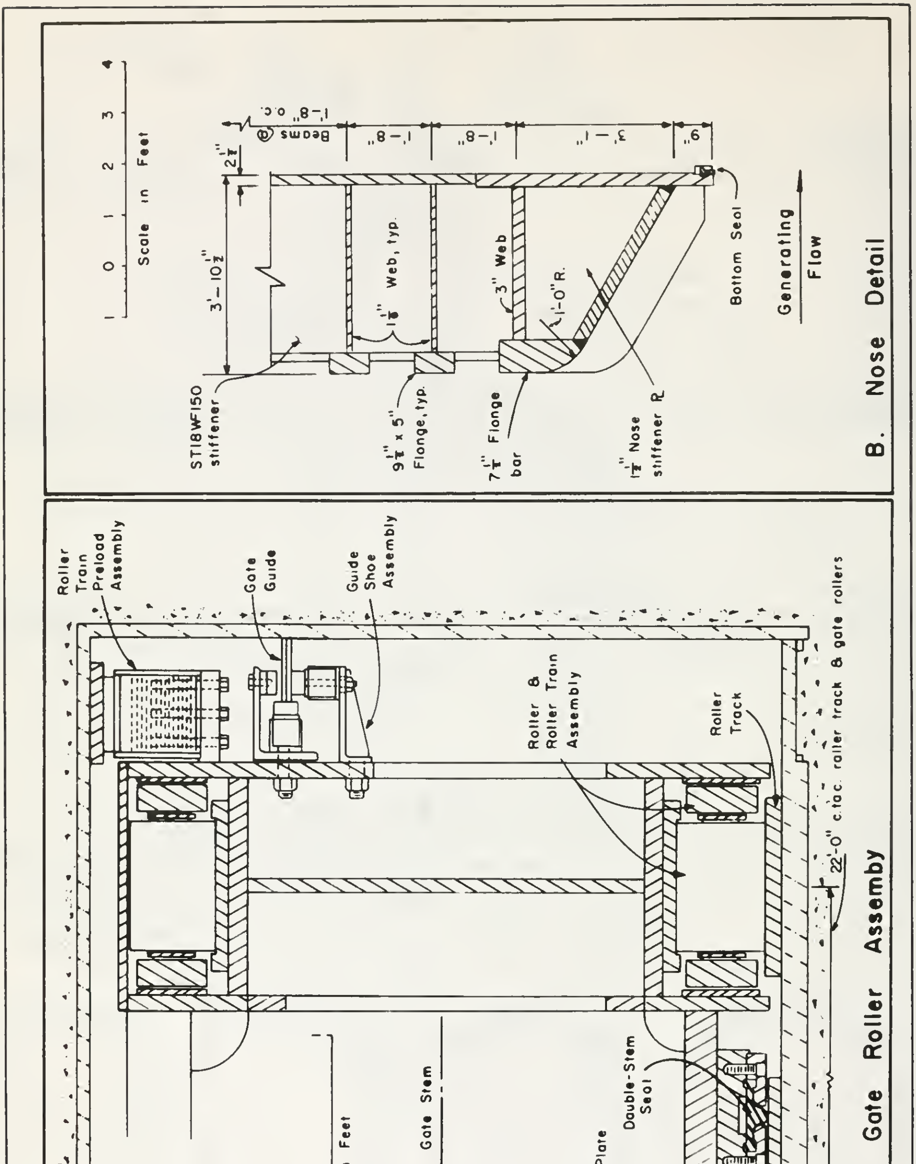

Figure 820. Gate Details

The maintenance chamber is located directly above the gate shaft (Figure 821). Its lower deck is at elevation 2,592 feet and the overhead is at elevation 2,643 feet. Working platforms for uncoupling the gate stem sections and performing other maintenance activities are located at elevations 2,601, 2,616, and 2,625 feet. These platforms also provide space for the hydraulic control console and the hydraulic and electrical systems. The chamber is entered through an access building above elevation 2,643 feet, and the various levels are reached by a spiral stairway.

During maintenance periods, the gate stem sections are removed one at a time and moved into the stem storage area by means of a 7½-ton stem-handling crane located on rails just below the plate girders that support the hydraulic cylinder. The chamber provides the on-site maintenance space for the gate. When all the sections are removed and stored, the gate is in its maintenance position and is supported on the special gate support base at elevation 2,592 feet. Raising and stem removal operations require approximately 40 hours.

The maintenance chamber has removable hatch covers which allow maintenance materials to be raised and lowered from above. These covers and the plate girders can be removed so that the gate can be taken off-site for major maintenance.

Tunnel

Description and Sizing. The 37,775-foot-long Angeles Tunnel has a diameter of 30 feet, as established in the aforementioned agreement between the City and the Department. The Department's original plan was to have a 17-foot-diameter tunnel, supplying a "once-through" flow to a 214 MW-Castaic Powerplant. The City agreed to provide all additional funding required to increase the tunnel size to a 30-foot diameter. This size tunnel enables Castaic Powerplant and Unit 7 Powerplant to generate at peaking capacity of 1,250 MW as well as pumping back at reduced dynamic head.

Alignment and Profile. The alignment of Angeles Tunnel (Figure 822) was chosen to avoid areas where extensive landslides exist and to provide adequate rock cover.

At the north portal, the tunnel invert elevation was controlled by the Pyramid interim dam and pool. The interim dam, a part of Pyramid Dam, diverted project water to a maximum elevation of 2,290 feet in order to deliver scheduled flows prior to completion of Pyramid Dam and Angeles intake. The north portal invert was set at elevation 2,260 feet, and a temporary intake was provided. This is considerably lower than the dead storage elevation of 2,345 feet.

The Angeles Tunnel has a slight shift in horizontal alignment where it crosses Cherry Canyon. The tunnel invert elevation at Cherry Canyon was set to provide sufficient rock cover and to minimize the length and grade of Osito Canyon adit. To obtain 60 feet of rock cover at Cherry Canyon, the Osito Canyon adit was sloped downgrade toward the Tunnel at 4.5%. Further lowering of the tunnel invert at Cherry Canyon would have resulted in an even longer more expensive adit at Osito Canyon.

At the crossing of Castaic Canyon, the horizontal alignment was established to obtain an adequate vertical rock cover of about 80 feet. Based on these considerations, the invert slope for the Tunnel was set at 0.00177 from the north portal to Station 178+00 and at 0.00222 from there to the south portal.

Tunnel Adits. All three of the tunnel adits are concrete-lined throughout, and provision for permanent access into the Tunnel through each adit is provided by means of a steel "dished head" door at each tunnel adit intersection plug. The adits are 11 feet wide by 13 feet high, except at the plug where, for structural reasons, the dimensions are reduced to 11 feet wide by 9 feet high.

The 2,585-foot-long Osito Canyon adit (Figure 823) is located approximately midway along the tunnel alignment. The 1,149-foot-long north adit is located approximately 5,655 feet from the north portal. The 1,350-foot-long south adit is located approximately 3,960 feet from the south portal.

Based on conventional methods of tunneling, Osito Canyon adit was necessary to facilitate excavation of the middle reach of the Tunnel in the limited time available. The south adit was constructed so that excavation muck from the south reach could be removed through the adit, rather than through the south portal. This freed the south portal area for construction of the connecting structure to Castaic Powerplant. The north adit accomplished a similar purpose by freeing the north portal area for construction of the tunnel intake structure.

Tunnel Portals. The south tunnel portal was excavated to a depth of 130 feet with 1:1 cut slopes. A large excavation was necessary to provide space for Castaic Powerplant penstocks, valves, and trifurcation structures.

A 3,333-foot, steel, tunnel liner extends from Castaic Canyon to the south portal where it joins the penstocks. Nominal reinforcing steel also was placed in the tunnel lining for a distance of 60 feet from the south portal where rock cover was only 60 feet. The portal face is supported by a reinforced-concrete, buttressed, portal structure. The upper backfilled portion of the structure headwall was designed for an equivalent fluid pressure of 60 pounds per square foot and the dead load of the structure. The rest of the structure was designed for the dead load plus an equivalent fluid pressure of 20 pounds per square foot.

At the north portal, a temporary umbrella-type structure was installed during construction to protect workers from rock falling from the steep slope above the portal.

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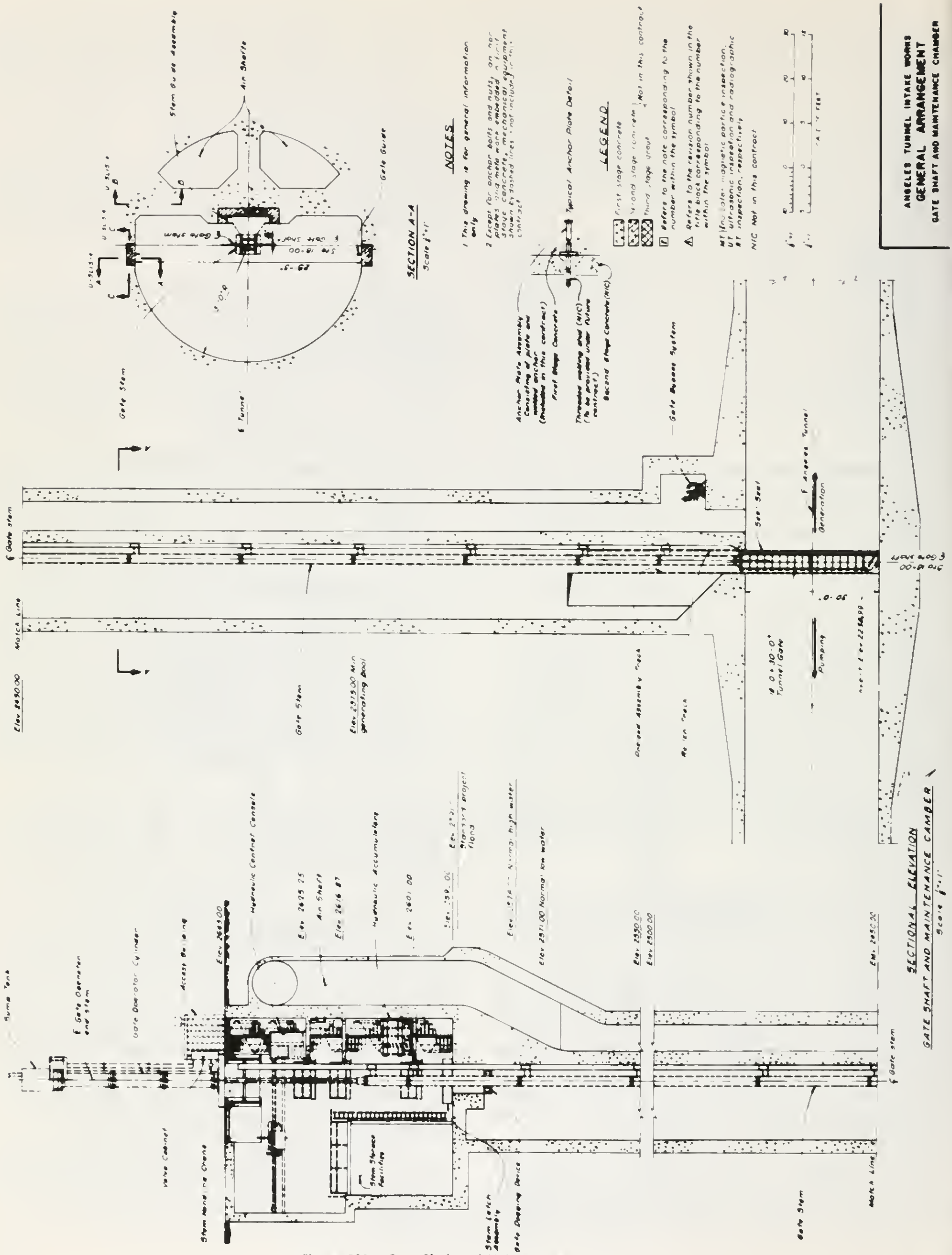


Figure 821. Gate Shaft and Maintenance Chamber

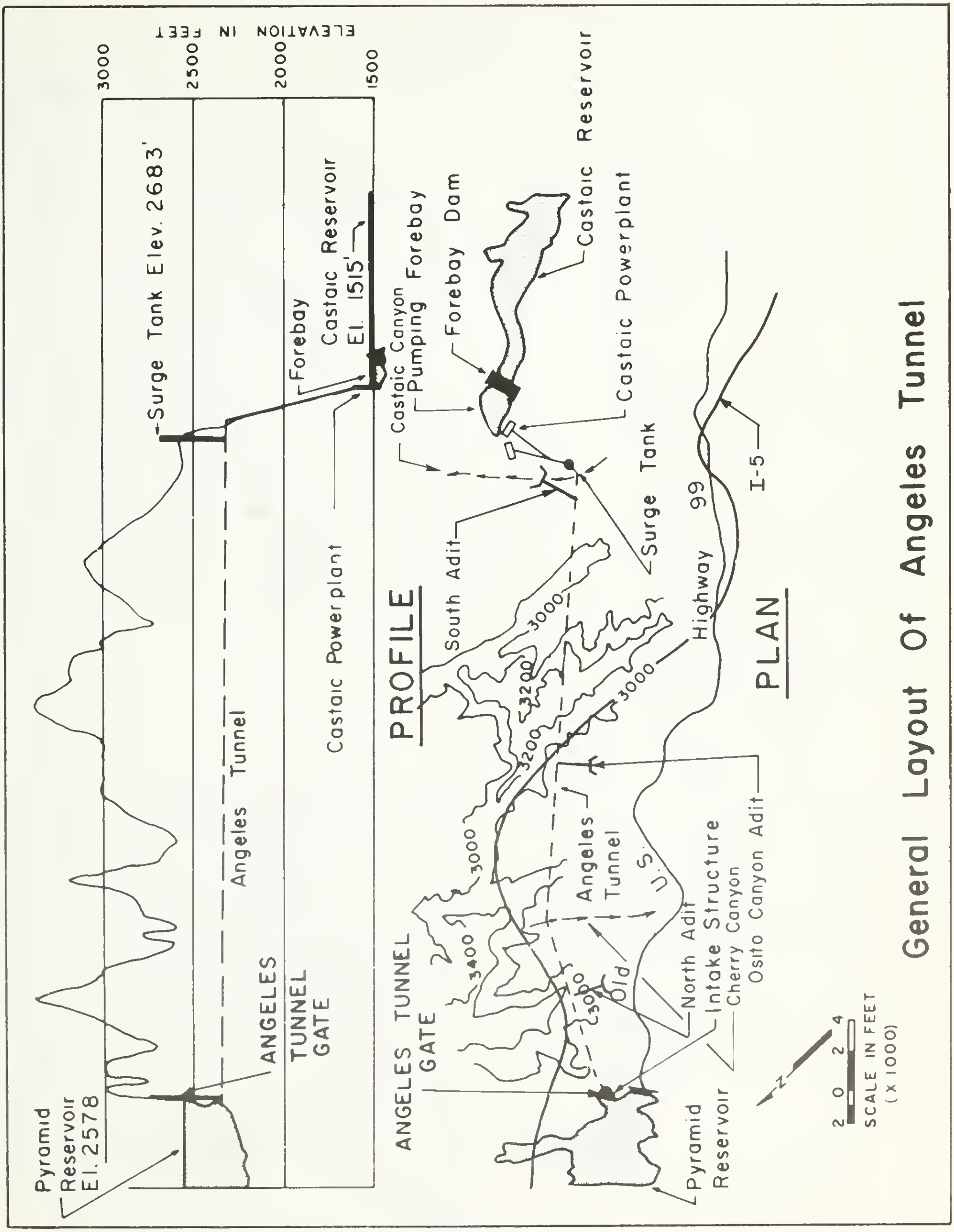


Figure 822. Angeles Tunnel Alignment

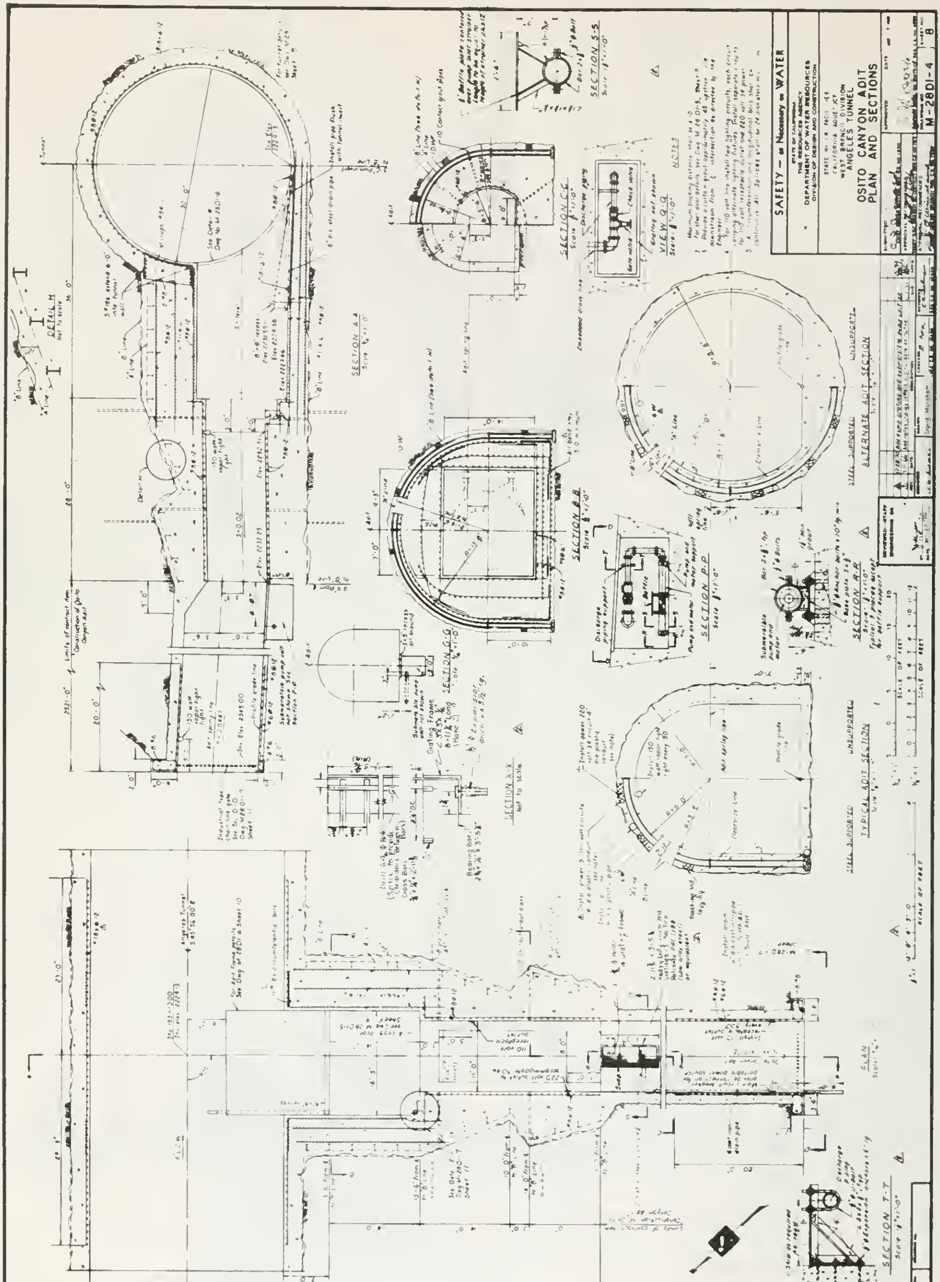


Figure 823. Osito Canyon Adit

Concrete Lining. The minimum thickness of the concrete lining was established at 15 inches. Where steel liner was used, the excavated tunnel diameter was increased to facilitate welding the steel liner sections and a greater concrete lining thickness was therefore necessary. A detailed stress analysis of the concrete lining revealed that the lining was over stressed in tension under internal hydrostatic loads, making cracking likely. Further study revealed that the stresses would be only slightly reduced by increasing the thickness of the concrete lining and therefore would be uneconomical. Reinforcing steel was considered to control cracking of the concrete and improve water tightness. However, this alternative was discarded because of the excessive amount of steel required. The only other alternative was to line the entire tunnel with steel. Again, the matter of excessive cost precluded the acceptance of this method. The problem therefore was presented to departmental consultants for recommendation.

The consultants advised that: (1) even though the concrete lining would ultimately develop minute cracks, the Tunnel would not be damaged; and (2) the concrete lining is ineffective in resisting internal pressure but resists external loads and improves the hydraulic properties of the Tunnel. Should the concrete crack, the internal pressure is transferred to the surrounding rock which is competent to resist this pressure. However, they advised using reinforced-concrete lining at the adit intersection. The 240 feet of tunnel adjacent to the intake structure was designed with a reinforced-concrete lining.

Steel Liner. A steel liner was used wherever the vertical rock cover was less than 60% of the internal operating head in feet, or wherever the horizontal rock cover was less than 200% of the internal head. Where the vertical rock cover was less than 40% of the internal head, or the horizontal rock cover was less than 120%, the steel liner was designed to take the full internal head. Where vertical rock cover was between 40% and 60%, the surrounding rock was assumed to take part of the load.

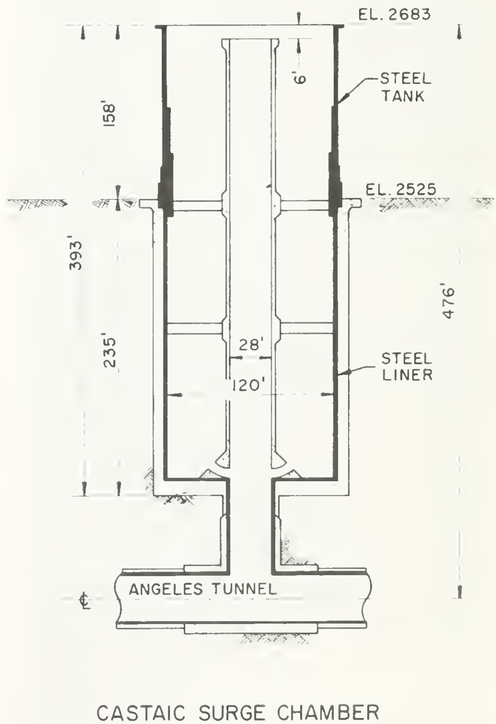
In order to prevent buckling of the steel liner when the Tunnel is dewatered, the steel liner was designed for external hydrostatic pressure equal to the depth of vertical rock cover above the Tunnel. About 400 linear feet of liner was installed at Osito Canyon, 1,040 feet at Cherry Canyon, and 3,333 feet at the south portal. Stiffener rings were used to strengthen the liner.

Grouting. Curtain grouting was specified at the intersections of the Tunnel and adits, and consolidation grouting was specified for the full tunnel length. Contact grouting was specified to fill voids between the concrete lining and surrounding rock and in the steel-lined reaches between the steel liner and the concrete.

Surge Chamber and Juncture Structure. The surge chamber and juncture structure (Figure 824) was designed and financed by the City but was included in the Department's Angeles Tunnel construction contract. The surge chamber is 120 feet in diameter and 383 feet in height, of which 225 feet is underground. The surge tank portion of the surge chamber is concrete- and steel-lined throughout, with the steel lining extending 158 feet aboveground. A 108-foot-long juncture structure is directly below the surge chamber on the tunnel alignment and connects the surge chamber and the Tunnel with a 28-foot-diameter riser. The juncture is heavily reinforced at the intersection with the riser. The riser extends 78 feet in height from the crown of the Tunnel to the bottom of the surge chamber.

Access Roads

Permanent, 28-foot-wide, asphaltic concrete-paved, access roads serve the south adit, the surge tank, and the south portal of Angeles Tunnel. The total length of access roads is approximately 2 miles.



CASTAIC SURGE CHAMBER

Figure 824. Surge Chamber

TABLE 16. **Major Contracts—Angeles Tunnel**

	Specification	Low bid amount	Final contract cost	Total cost—change orders	Starting date	Completion date	Prime contractor
Angeles Tunnel	66-22	$95,039,650	$105,565,117	$4,704,897	9/26/66	1/31/72	Shea, Kaiser, Lockheed, and Healy
Angeles Tunnel intake works	70-23	4,400,298	5,019,889	292,642	10/ 1/70	5/10/72	Shea-Kaiser-Healy
Completion of Angeles Tunnel intake works and Pyramid Dam outlet works	71-10	4,552,630	4,902,095	347,981	7/ 6/71	4/18/74	Wismer & Becker Contracting Engineers

Construction

Contract Administration

General information about the major contracts for the construction of the Angeles Tunnel is shown in Table 16. The construction of the Tunnel and appurtenances was accomplished under the provisions of three major contracts. These were Angeles Tunnel, Specification No. 66-22; Angeles Tunnel Intake Works, Specification No. 70-23; and the Completion of Angeles Tunnel Intake Works and Pyramid Dam Outlet Works, Specification No. 71-10.

Tunnel

Portal and Open-Cut Excavation. The Castaic and Ridge Basin group sandstone and siltstones at the north adit, Osito adit, south adit, and south portal areas were excavated using bulldozers equipped with rippers and with scrapers. At the north portal area, the hard, slightly weathered, Pyramid argillites had to be drilled and shot before they could be dozed downhill, loaded into trucks, and hauled to designated areas.

Construction of Tunnel Adits. The contract specifications required that the north, Osito, and south adits be constructed so that the Tunnel could be driven from four headings concurrently until satisfactory progress with fewer headings was demonstrated.

As soon as the portal area had been opened in November 1966, the contractor started driving Osito adit. Driving of the north and south adits started soon afterward (Figures 825 and 826). Driving of the south adit for a length of 1,223 feet was completed in February 1967 and Osito adit, with a length of 2,518 feet, a month later. The north adit, which is 1,147 feet long, also was completed in February 1967.

The adits were driven full-face using conventional methods of tunneling. The drill-shoot-muck-support cycle was accomplished using rubber-tired diesel equipment. Muck was deposited in the designated spoil area outside the adit portals. A nominal 17-foot-wide by 19-foot-high horseshoe section was used when driving the adits. Average rate of progress for a three-shift day six-day week was 30 feet per 24 hours. Tunnel rock support in the adits consisted of 8M34.3 steel ribs set on 4- and 5-foot centers. Steel pipe collar braces and timber blocking, timber lagging, and footblocks were used.

Figure 825. Excavation of South Portal—South Adit

Figure 826. Preparation of South Portal—South Adit for Gunite

Main Tunnel Excavation. The Tunnel (Figures 827 and 828) was driven using conventional top heading and bench tunneling methods. Driving of the top heading of Angeles Tunnel commenced in November 1966 and was holed through in March 1968. The top heading driving cycle consisted of a drill-shoot-muck-support-type operation. As many as five headings were driven simultaneously. Most of the top heading was completed before excavation of the bench commenced.

All top heading excavation was made from 10 job-built rubber-tired jumbos. These tunneling jumbos were mounted on truck chassis. Two jumbos worked side by side at each heading. Explosives were loaded in the drill holes from the jumbos under illumination from arc lights. The two jumbos were moved about 1,200 feet down the Tunnel before the round was fired.


Figure 827. North Face of Angeles Tunnel


Figure 828. Main Tunnel—View of North Face

The rate of advance in each top heading depended on the type of rock or ground encountered. In sandstone, 25% of tunnel length, the advance averaged about 28 feet for a 24-hour day. In siltstone, 37% of the tunnel length, the advance averaged about 25 feet. In sandstone-siltstone, 29% of the tunnel length, the advance averaged about 30 feet. In areas of fault gouges, the advance was only about 17 feet. These rates are based on a six-day week with three shifts per day.

Forty-five percent semigelatin dynamite was used initially for blasting, but later this was changed to a less expensive 60% dynamite fired by zero to ten-second-delay electric blasting caps. The average powder factor was 2 to 4 pounds per cubic yard of excavation.

After the heading had been mucked out and dressed down, two tractors equipped with front-end loaders and rear-mounted hydraulic backhoes made the final excavation for the steel wall plates. The wall plates, two 15I50 beams welded together with gusset plates, were placed on bags of "Sac-Crete" used as leveling blocks. The steel tunnel supports, which consisted of two arch rib segments, were made from W10x40 structural steel. They were set on the wall plates by working from the drilling jumbos. They were placed on 4- or 5-foot centers depending on ground conditions. The arch ribs were tied together with bolt collar braces inside lengths of 3-inch pipe. Steel and timber lagging and timber blocking were installed between the rib sets and the rock.

After the heading had been advanced some distance, it was determined that the ground was exerting more pressure than anticipated on the tunnel supports. The sets were strengthened by placing concrete in the span between sets and extending 4 feet above the wall plates, resulting in a heavy wall-plate section that acted as a continuous beam.

Excavation of the bench was started before the top heading had been completed. The bench excavation was a drill-shoot-muck-gunite-type operation. A 5-foot by 7-foot pattern was drilled as shown on Figure 829. Excavation of the blasted material was accomplished by large dozers equipped with two rear-mounted rippers and side-slope blade attachments for trimming the sidewalls. Rate of advancement for the bench excavation varied widely from 20 to 305 feet per 24-hour day per heading.

The exposed excavated area was coated with a nominal 1 inch of gunite. This application controlled the progressive loosening of rock particles, minor slaking, and reduced cleanup problems prior to the placing of concrete lining.

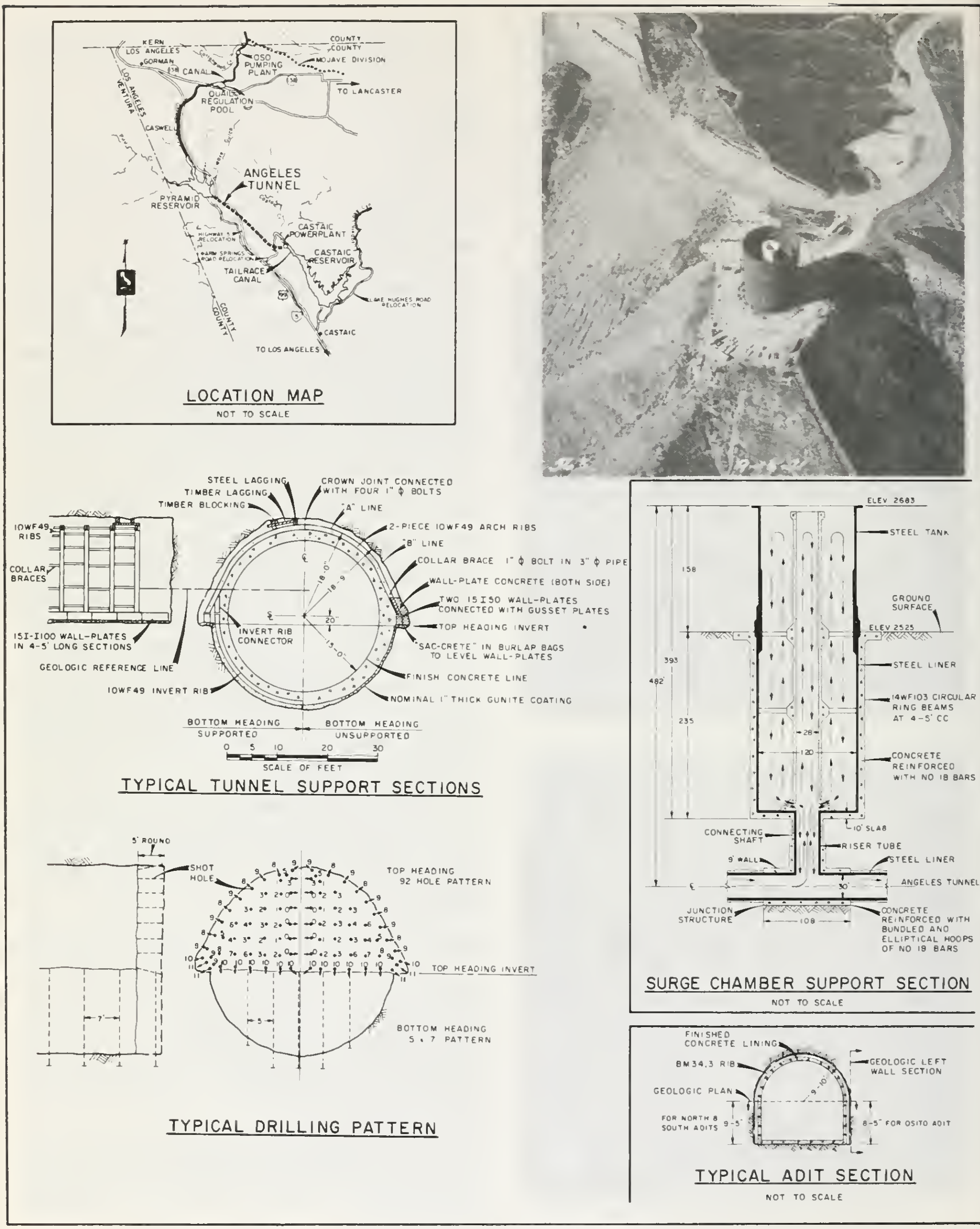


Figure 829. Angeles Tunnel Details

The invert was unsupported except in relatively short sections of tunnel where poor ground conditions were encountered. In these areas, W10X49 invert ribs were used resulting in a full-circle support system. Spacing of these ribs varied from 5 to 12 feet depending on ground conditions.

Ground Water and Gas. Both ground water and gas were encountered in the driving of Angeles Tunnel, although neither presented serious construction problems.

Ground water at the different headings was minor and was readily handled by the drainage systems. The gasses encountered during driving were methane and hydrogen sulfide. The hydrogen sulfide gas was in such small quantities that it did not present a problem to the operation; however, methane gas was a continuing hazard. An automatic alarm system was installed in each air exhaust line which was triggered whenever the exhaust air contained 2% or more of methane gas. In addition, gas readings were taken periodically in each work area.

One methane gas explosion occurred while driving the Tunnel just north of the intersection with Osito adit. The explosion, which occurred during the night shift, was due to open-flame cutting and resulted in hospitalization of four workmen with minor burns. Damage to the work was negligible.

Survey Control. Exterior vertical and horizontal survey controls were established by the Department using conventional surveying methods. The contractor used laser beam survey instruments for survey control inside the Tunnel.

Steel Liner. Prior to commencing concrete lining of the Tunnel, steel liners were installed. Liner was required at Cherry Canyon, Osito Canyon, and from just upstream of the surge chamber to the south portal. The steel plates varied in thickness from 1 to $1^{15}/_{16}$ inches. The plates were hauled to the job site on semitruck and trailer haul units. Two assembly yards were established near the north adit and the south portal, where individual plates were assembled and welded into circular cylinders with a 30-foot inside diameter. Each was approximately 30 feet long (Figures 830 and 831). Stiffener rings were welded on the outside of the liner plate for added resistance to external hydrostatic pressures.

Initial steel liner installation started from the south portal (Figure 832). The 30-foot-long cylinder "cans" were hauled into the Tunnel on a carrier jumbo, positioned, and welded together. Steel liner cylinders for Osito and Cherry Canyon reaches, which were fabricated at the north adit yard, were hauled to the north portal on special heavy-duty "low-boy" trailers pulled by diesel truck tractors. They were then transferred onto the special carrier jumbo and hauled into the Tunnel. The space between the outside of the steel liner and the excavated tunnel surface was backfilled with structural concrete.

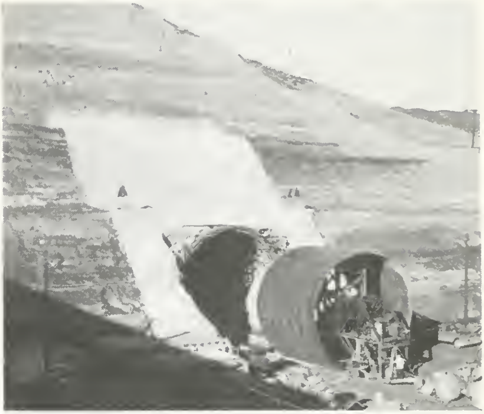


Figure 830. South Portal View Looking at Can S-4

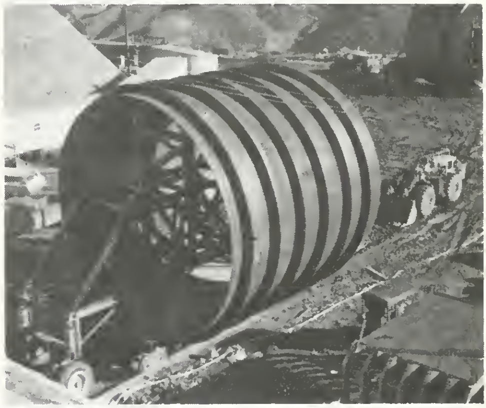


Figure 831. South Portal Can S-4 on Tunnel Transporter

Figure 832. South Portal Tunnel Steel Liner

Concrete Lining. The Tunnel was lined with concrete in two operations. Specifications required that the 90-degree quadrant invert be placed before the sidewalls and arch and that the concrete be 3-inch maximum size aggregate at a placement temperature no greater than 50 degrees Fahrenheit.

A total of 32,798 linear feet (67,000 cubic yards) of invert (Figure 833) was placed using a job-designed, self-propelled, rail-guided, continually moving slip form and placing train that could extend for 1,000 feet. In addition to the slip form, the train contained a conveyor-belt delivery system made up of ten 100-foot-long sections and several finishing platforms suspended from a monorail attached to the conveyor belt sections.

Concrete was delivered from the south adit batch plant (Figure 834) to the receiving hopper at the end of the lining train in specially designed 12-cubic-yard, agitating-concrete, rail cars propelled by a diesel tunnel locomotive.

After the invert paving had been completed to the north end of the Tunnel, lining of the arch and sidewalls was started. A 600-foot-long lining train was used, made up of fifteen 40-foot-long collapsible forms designed especially for the job (Figure 835). The form-moving jumbo rode on rails laid during the invert paving.

Concrete was again delivered from the south adit plant to the concrete pumping system in concrete rail cars. The pumping system consisted of two pumpcrete machines working side by side to feed the 10-inch-diameter slickline.

Batching, Mixing, and Ice Plants. The batching and mixing plant consisted of an 8½-cubic-yard tilting mixer; rewashing and finish screens; and weighing, metering, and blending hoppers. The batcher system consisted of an 8½-cubic-yard batcher coupled with two silos (500–600 barrels) for cement and pozzolan with electric, over-air discharge, clamshell-type gate with 12-foot - 6-inch clearance.

The ice plant, which was adjacent to the batch plant, consisted of an ice batcher with a 50-cubic-foot capacity with direct discharge into a mixer; a 360-gallon, automatic, water weight batcher with control; and an ice plant with a 300-ton-per-day capacity with a 100-ton ice storage bin. The units were automatically controlled.

Concrete Materials. Type V low-alkali cement was delivered in bulk to the job site in truck-tractor rigs. Pozzolan was delivered in the same manner as the cement.

Zeecon R-40 was used as the water-reducing agent. The required sands and aggregates were obtained from the contractor's processing plant located in Castaic Canyon. Water used for concrete mixing, aggregate washing, and other tunnel use was obtained from Castaic Creek. The contractor had developed several wells and installed several large pumps in the vicinity of his aggregate source.

Grouting. Contact and consolidation grouting of the Angeles Tunnel was performed from rubber-tired jumbos using "Moyno" grout pumps under the direct supervision of department personnel.

Figure 833. Wooden Float Finisher Applying Bull Float to Invert

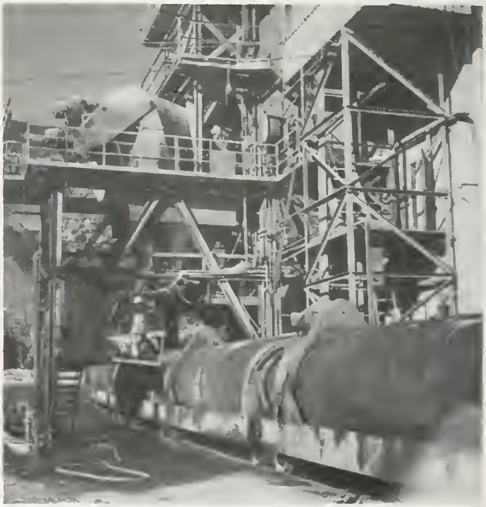


Figure 834. View of Contractor's Batch Plant at South Adit

Figure 835. View of Contractor's Tunnel Arch Forms

Figure 836. Excavation of Surge Chamber

The grout was premixed at a small plant set up near the south adit batch plant and hauled into the Tunnel in the same concrete transporting cars used for the concrete.

Surge Chamber

Excavation. Excavation of the surge chamber was started in March 1967 after the tunnel top heading had been driven approximately 900 feet from the south portal where the surge chamber intersects the Tunnel. The nominal 139-foot-diameter excavation was made in stages. First, a chamber was excavated to about 13 feet below the surface of the ground. Then a 6-foot-diameter vertical shaft was drilled to intersect the Tunnel. Two dozers equipped with rear-mounted rippers ripped and pushed the rock into the 6-foot shaft (Figure 836). The accumulated spoil which dropped into the Tunnel was loaded into Athey Wagons by a 48-inch belt loader and hauled to the south portal disposal area. The shaft was sunk in 5-foot increments. After excavation and trimming had been completed, W14X103 circular steel ring support beams were installed on 4- to 5-foot spacing.

After the surge chamber and riser excavation had been completed, the bottom half of the juncture structure was excavated along with the tunnel bench.

Reinforcement. As soon as all excavation had been completed, the steel supplier started installing 16 million pounds of No. 18 (2¼ nominal diameter), high-strength, steel reinforcing bars. The detailing and installing of these large bars were so intricate that a scale model of the juncture structure was built to assist in visualizing how to place the steel.

Steel Liner. With the placement of reinforcement steel well under way, the supplier started installation of the juncture structure riser and surge chamber steel liner. Structural concrete backfill between the excavation surface and steel liner followed the liner erection as closely as possible without creating interference with the concrete placing operation.

Thus, construction of the surge chamber advanced in increments: first, the installation of reinforcing steel, then the installation of the steel liner, and finally the placing of concrete.

Concrete for the juncture structure and surge chamber was manufactured at the south adit batch plant and transported to the ground-level area at the surge chamber by a fleet of transit mix trucks. Placement was by a number of 10-inch-diameter steel drop pipes located around the perimeter of the chamber and inserted between the excavation and the steel liner (Figure 837).

Intake Works

Excavation. The major construction was under Specification No. 70-23. Excavation for the foundation of the intake structure at the entrance to Angeles Tunnel started March 2, 1971, was not extensive, and was completed in seven days. The air-shaft extension excavation also was minor, although it required some drilling and shooting.

Excavation was started for the gate shaft by drilling an NX pilot hole which was difficult to keep on line. Three attempts were required before the hole was completed satisfactorily.

A 6-foot-diameter raise for the gate-shaft excavation


Figure 837. Concrete Placement in Surge Chamber Wall

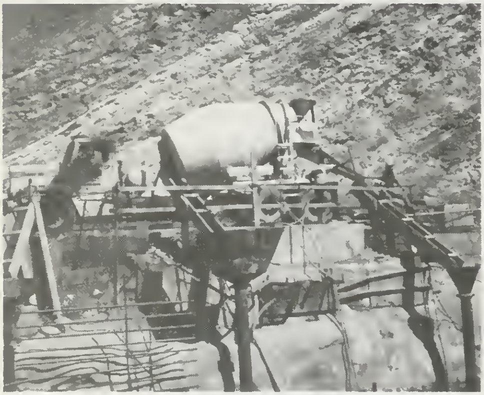


Figure 838. Placing Concrete in 10-Inch Drop Tubes


Figure 839. Reinforcing Steel in Gate Shaft

began October 20, 1970 from a two-man drilling cage, hoisted by a cable through the pilot hole with a winch located at the gate-shaft bench. The raise excavation proceeded upward along the pilot hole from the tunnel crown at about elevation 2,290 feet to the gate-shaft bench at the surface. This operation consisted of a drill-shoot-muck cycle. After drilling and loading were completed, the man-cage was taken into the Tunnel away from the blasting area. The muck dropped down the raise to the Tunnel and was hauled to a spoil pile near the north portal by a front-end loader. The last 20 feet were drilled and shot from the surface. The raise was completed November 2, 1970, for an average progress of 14 feet per eight-hour shift.

Excavation for the gate maintenance chamber was driven from the gate-shaft bench at elevation 2,642 feet to elevation 2,591 feet, a total depth of 51 feet. Average progress was 1.6 feet per ten-hour shift.

In excavating the gate maintenance chamber and gate shaft, a backhoe was lowered after each blast and pushed the debris into the disposal shaft. A rubber-tired front-end loader hauled the excavated material from the Tunnel to a designated waste area near the north portal. The excavated surfaces were secured with rock bolts, wire mesh, and shotcrete.

Excavation of the gate transition structure required the removal of some of the existing arch tunnel ribs; shooting of rock; removal of wall plates; and reinforcing portions of the tunnel crown by use of rock bolts, wire mesh, and shotcrete.

Concrete Structures. Major concrete structures include a gate transition structure, gate shaft with twin air shafts, gate maintenance chamber, air-shaft extension and outlet structure, and a dual-stage intake structure with an interim intake.

Gate Transition Structure. Wooden forms were fabricated in sections at the carpenter shop and assembled in place. One-inch steel liner plate was embedded on either side of the gate slot, and a 1-inch steel impingement was embedded downstream of the gate slot opposite the gate bypass pipe outlet. The transition was heavily reinforced with No. 18 rebar hoops butt-welded and X-rayed in place.

The transition invert was placed by pumping concrete through the Tunnel with a concrete pump, and then the surface was steel-troweled. Concrete was placed in the walls and crown of the transition by transporting concrete in transit mix trucks to the top of the gate shaft where it was discharged into one of four 10-inch pipes and allowed to drop about 350 feet to in-place forms (Figure 838). From the bases of the four drop pipes, the concrete flowed to final position under the head in the pipes assisted by vibration. Horizontal movement was approximately 50 feet. The impact from the 350-foot drop caused the concrete to swell and flow away from the pipes in a homogeneous mass with no evidence of segregation. Vibrators helped to move the concrete from the pipe into final position. Slump loss due to the drop of concrete through the pipe was about 1 inch.

The first invert placement in the gate transition was made on April 1, 1971, and the structure was completed to elevation 2,335 feet on December 14, 1971.

Gate Shaft With Twin Air Shafts. Steel forms, hinged and collapsible to facilitate stripping, were utilized in three separate 20-foot sections: one for the gate shaft and two for the air vents.

Concrete was placed in the gate shaft by discharging from transit mix trucks into the six 10-inch drop pipes located uniformly around the shaft. An additional pipe was placed at the intersection of the gate shaft and air-shaft forms and 1½-inch maximum size aggregate concrete was substituted for 3-inch maximum size aggregate concrete because of a heavy concentration of reinforcing steel in that location (Figure 839).

Gate Maintenance Chamber. Gate maintenance chamber concrete was used in the structure from the top of the gate shaft at elevation 2,556 feet to the gate-shaft bench at elevation 2,643 feet.

The gate-shaft steel form was utilized up to elevation 2,585 feet. Beginning at elevation 2,556 feet, the air shaft (Figure 840) converges from two vents to a single vent, ending in a 10-foot circular section. This section of air shaft and the gate maintenance chamber walls were wood formed.

Concrete was placed in a similar manner as in the gate shaft with 10-inch drop pipes. Some concrete also was placed with a crane and concrete bucket.

Air-Shaft Extension and Outlet Structure. The air-shaft extension, which is 90 feet in length, changes from the vertical air shaft into a 10-foot-diameter horizontal tube (Figure 841). This tube was formed with wood fabricated in sections at the carpenter yard.

Concrete for the air-shaft extension was placed by crane and bucket.

Dual-Stage Intake Structure. The Angeles Tunnel intake is a concrete structure forming a transition from the four-barrel vertical intake to the horizontal Angeles Tunnel. This structure also provided an interim intake complete with trashracks, slide gate, and water-level recorder. The first-stage contract under Specification No. 70-23 completed the intake to elevation 2,335 feet. The tower was completed to elevation 2,357 feet under Specification No. 71-10.

First-stage concrete was placed in the intake structure when foundation backfill began. Added excavation was required to reach sound rock, and a total of 6,800 cubic yards of backfill concrete was placed. This was 2,800 cubic yards more than the estimated quantity.

The first major structural concrete placement was for the intake invert and was difficult. Three concrete pumps were set up with slicklines to pump to the downstream side and work upstream. From the upstream face for a distance of about 950 feet, 3-inch

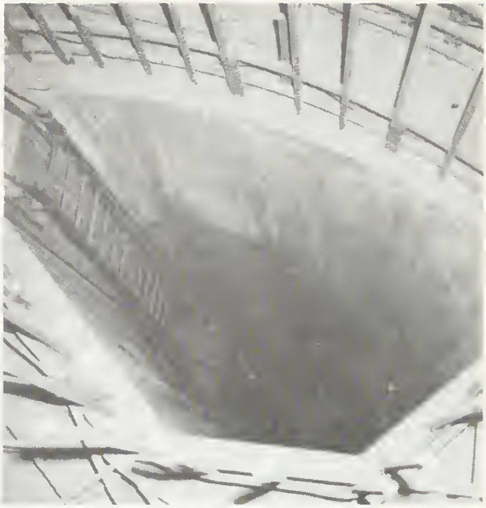


Figure 840. Left Air Shaft

Figure 841. Air Shaft Extension Outlet

maximum size aggregate concrete was placed by the crane and bucket method. This method could not be utilized downstream because of the congestion of closely spaced reinforcing steel in the walls.

In the horizontal and radial section of the intake, the forms were designed to stack in sections. This did not allow form stripping to take place until the entire section was completed.

The last concrete for the first-stage intake was placed on October 22, 1971, and the intake was completed on December 31, 1971 (Figure 842).

The second stage of the intake structure required the placement of about 1,300 cubic yards of reinforced concrete in a cap section and in trashrack support frames on top of the first-stage intake structure. Complicated forming of many curved surfaces was required 50 feet above grade. The support frames are heavily reinforced, and the placing of concrete and embedded anchor bolts was difficult.

Steel forms were used for most of the intake structure concrete. Some surfaces such as fillets and panels were formed with wood, covered with either masonite (flat surfaces) or sheet metal (fillets), to produce the required finish.

Concrete Placement. The concrete plant was used earlier for the Angeles Tunnel work and is described in previous sections. The plant was relocated near the north portal of Angeles Tunnel during construction of the intake. It was later moved immediately south of the contractor's field office, and concrete for the gate shaft was produced there.

Aggregates were hauled to the batch plant from Castaic Creek in end-dump trucks.

Grouting. Grouting of the transition section of the gate shaft-tunnel intersection under Specification No. 70-23 was accomplished in three stages. After concrete placement, the transition area was contact grouted. At each end, the grouting was extended 20 feet beyond the contact between the transition and the tunnel lining. During contact grouting, a large grout take occurred in the joints between tunnel lining and transition.

When the gate shaft was lined to elevation 2,330 feet, the second stage of grouting occurred. Consolidation grout holes were drilled and grouted. The split-spacing method was continued during this operation, and the use of contact grouting holes also was continued. In general, a pressure of 30 pounds per square inch (psi) was used in grouting of this area. The grout mix proportion, designated by the ratio of water to cement by volume, was varied from 7:1 to 1:1 to meet the characteristics of the area. The grout take was small.

The third and final stage of grouting was the contact grouting behind the steel lining in the transition structure. An aluminum powder additive was used to provide nonshrink grout under the steel liner. The liner was sounded to locate voids, drilled, and fitted for ⅜-inch pipe valves. Except under the gate-slot floor area, little grout was required behind the steel liner. Upon completion, the grout holes were welded shut and ground smooth.

A series of grout pipes was placed around the interim intake. These later were used for grouting after the plug concrete had been placed.

Mechanical Installations. The major mechanical installations were made under Specification No. 71-

Figure 842. Looking East at Intake Structure

Figure 843. Filling Closure Plates on Floor of Gate Transition

Figure 844. View of Roller Track Milling Machine in the Right Gate Slot

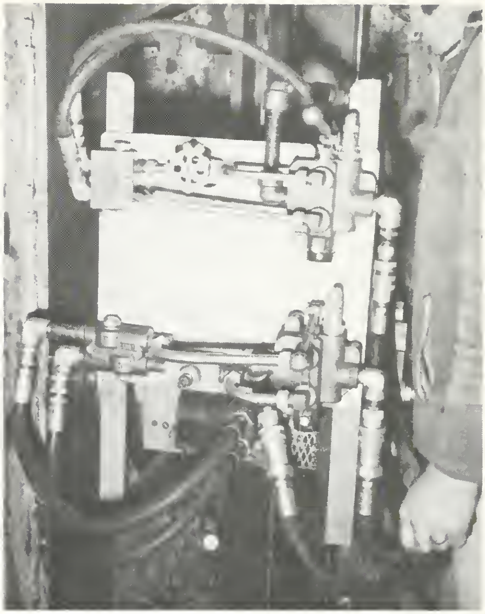


Figure 845. Cutter Head and Hydraulic Controls for Gate Roller Track Milling Machine

10. The principal item was the construction of a tunnel intake gate and related gate-shaft metalwork.

The most formidable task encountered in completing the Angeles Tunnel intake was the installation of the metalwork in the gate slot and gate shaft to the specified tolerances. The plans called for all metalwork to be located within a tolerance of $\pm \frac{1}{64}$ of an inch, and the requirements for the gate roller tracks were: (1) at any given point, the surface should not deviate from a true plane at a rate greater than 0.002 of an inch per foot; and (2) deviation from a true plane should not exceed 0.006 of an inch in a 10-foot length.

The gate-slot metalwork consisted of the roller tracks, seal plates, preload tracks, and gate guides. It was accurately set and held in position while blockout concrete was placed. The concrete was placed in three 10-foot lifts and, during each placement, dial indicators were used to check for any movement of the metal. On the first placement, the maximum movement of the roller track and seal plates was 0.002 of an inch, while a movement of 0.009 of an inch was detected for the preload track. Criteria of 0.002 of an inch maximum for tracks and seals and 0.005 of an inch for preload and guide sections were established for the subsequent placements. After the concrete placements were completed, the metalwork was checked and found to be within specified tolerances.

As a final operation in installation of the gate-slot metalwork, it was necessary to weld closure plates between the newly installed metalwork and the existing liner plate (Figure 843). This required full penetration welds to be made within 18 inches of the gate roller tracks and sealing surfaces in material 1 inch thick. When these welds were made, the structural members to which the tracks and seals were attached pulled and warped due to the thermal stresses. As a result, the tracks and seals were pulled downstream from 0.02 to 0.05 of an inch. To meet water commitments, it was necessary to fill the Tunnel on November 11, 1972. Because of this, the contractor was permitted to complete the closure welds and apply a first coat of epoxy to the liner plate without correcting the tracks and seals deformation. This was delayed until the Tunnel was again dewatered.

The contractor arranged to mount a milling machine in the gate slot during the next dewatering period to mill the track and seal surfaces to tolerance. The milling machine consisted of a 10-inch, 100-pound, wide-flanged section, 40 feet long with two precision-machined 1-inch-diameter bars let into the sides four ways. This was bolted to the gate-slot liner plate with angle clips at 18-inch centers (Figures 844 and 845). The carriage travel was controlled by a 40-foot-long lead screw powered by a hydraulic motor. The 16-inch cutting head also was powered hydraulically.

During the final dewatering period, the milling machine was set in position. Five days of adjustments were required before the first cut was made (on the right roller track). The milling was completed six days later, after an average of 0.060 of an inch of metal was removed. The final measurements indicated excellent results. The quality of the job was verified by an inspection of the downstream face of the tunnel gate on April 3, 1974. At that time, the gate was under a head of 250 feet of water, and the leakage beneath the gate was less than 5 gallons per minute (Figure 846).

From November 1972 through March 1973, the gate-shaft metalwork (gate guides and stem guides above the Tunnel) was set in place and the second-stage concrete was placed (Figure 847).

The Angeles Tunnel gate, which is a flat-leaf coaster type with two continuous roller trains on each side, was fabricated in Japan. It was delivered to the site on December 11, 1972 and placed in temporary storage on old Highway 99. On January 23, 1973, the lower half of the gate was moved to the gate maintenance chamber and set in erection position just upstream from the gate slot. The lower half of the gate weighed approximately 72 tons, slightly more than the top section (Figure 848). The gross axle load for the lower gate half and nine-axle transporter was 234,510 pounds, which is the heaviest allowed on the state highway system.

The gate was erected in a temporary position upstream from the gate slot allowing work to continue in the gate shaft. The bottom half of the gate was set into place and pinned to the gate support base, and the upper half then was lowered into place and bolted to the lower section. Lateral support for the gate was

Figure 847. Stem Guide Blockout Formwork

Figure 846. Seepage in Right Corner of Tunnel Gate

Figure 848. Lower Half of Gate Being Raised to Vertical Position

provided by cable ties upstream and downstream. The cables were attached at the gate maintenance chamber walls to wall reinforcing steel, which was exposed by chipping out sufficient concrete to permit attachment of the cables. These cables with come-alongs were later used to pull the gate into position over the gate slot.

Assembly of the gate and hydrostatic testing of the gate seals were completed in April 1973. On May 3, 1973, the gate was fully lowered into the gate slot.

The gate operator is a 34-foot-long, 32-inch-diameter, hydraulic cylinder supported at the top of the gate maintenance chamber by two 8-foot-deep plate girders (Figure 849). With a pressure of 1,550 psi on the rod end, it is capable of exerting a lift of just over 1,000,000 pounds. The gate operator was delivered to the job site on March 12, 1974.

The gate-operator hydraulic system is comprised of pumps, control cabinet, valve cabinet, appurtenant piping and hydraulic components, and a nitrogen-over-oil accumulator system.

Many difficulties and delays were encountered during the shop fabrication of the hydraulic system. Because of these delays, the system was not delivered to the job site until December 18, 1973, and it was necessary for the contractor to supply a temporary hydraulic system for installation of the gate in the spring of 1973.

The gate stem is comprised of 14 sections. Each length was fabricated by welding together two W21X142 structural shapes of A36 steel. Each stem joint is made up with fourteen $1\frac{3}{4}$-inch stud bolts made of precipitation-hardened stainless steel with a tensile strength of 150,000 psi. When each stem connection was made up, each stud was pretensioned to 128,000 psi by means of a portable, air-operated, hydraulic-tensioning device (Figure 850).

From April 1973 until January 1974, when installation of the permanent system was started, the temporary system remained connected for use in case an emergency closure of the tunnel gate was necessary. Installation of the permanent system continued from January 28, 1974 to March 12, 1974, when testing of the system was started. During the period of installation of the permanent system, the temporary system was not usable. However, the gate was operable in case of emergency. It had been lifted and the dogs retracted, and it was supported by the hydraulic oil in the operator cylinder.

Bypass piping was installed under the contract for the Angeles Tunnel intake works, Specification No. 70-23. The two valves, which are 24-inch spherical plug valves, were installed under contract (Specification No. 71-10). Makeup of the valves to the existing piping was made during the final dewatering period, the same period that milling was done.

These valves are hydraulically controlled from the gate maintenance chamber.

Electrical Installations. Embedded conduit in the gate maintenance chamber, control building, reservoir gauging station, gate shaft, and the gate-shaft bench was installed under Specification No. 70-23. The completion contractor installed all the required surface conduit runs, electrical wiring, control cabinets, and all devices required to complete the electrical installation for the Angeles Tunnel intake works.

Electrical work was completed as equipment was installed and made ready for operation.

Figure 849. Completed Hydraulic Operotor for the Tunnel Gate

Figure 850. Eiach Tensioners Used to Tension Tunnel Gate Stem Flange Studs

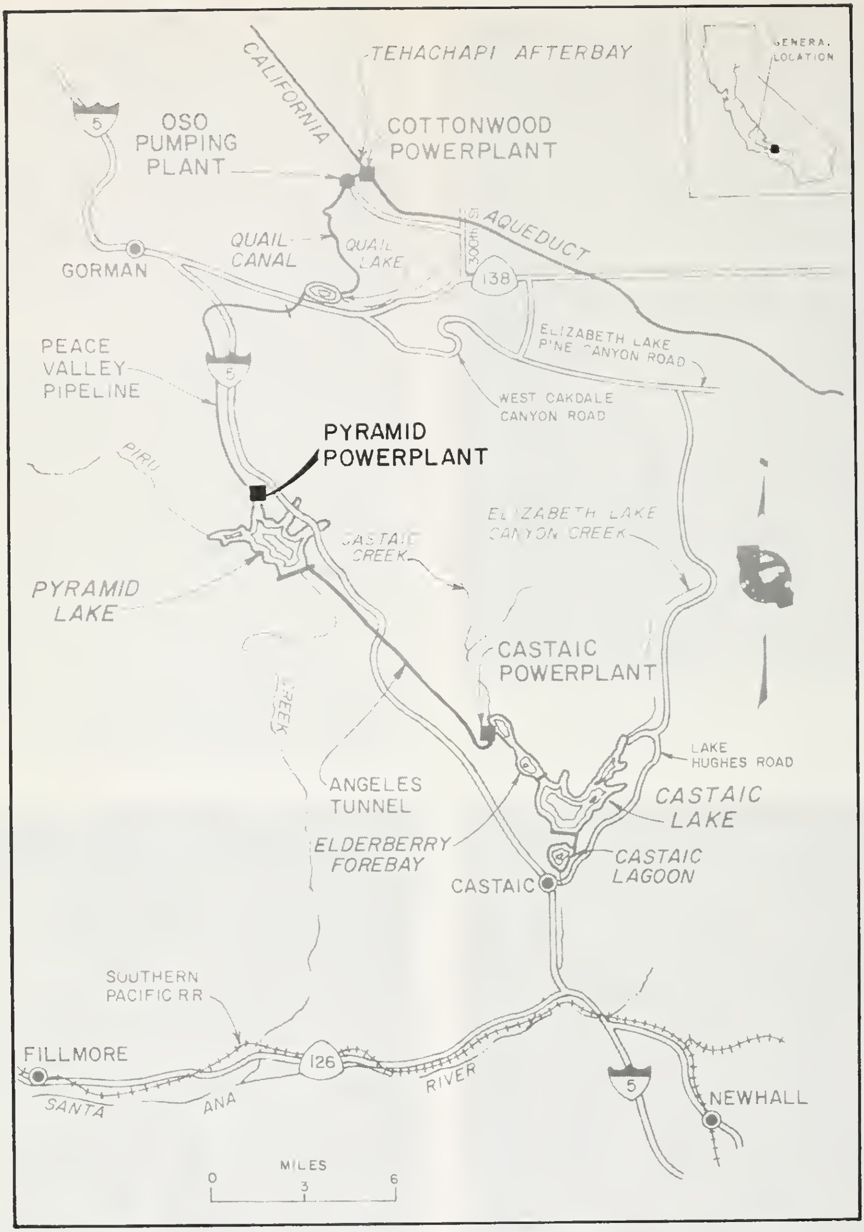


Figure 851. Location Map—Pyramid Power Development

CHAPTER XVIII. PYRAMID POWER DEVELOPMENT

General

Location

Pyramid Powerplant will be located at the upper end of Pyramid Lake, approximately 8 miles south of Gorman and 55 miles north of Los Angeles. This site is on the west side of Gorman Creek and west of Interstate Highway 5 (Figure 851).

Purpose

This powerplant will generate electrical energy by utilizing the available head in the California Aqueduct from the end of the lower Quail Canal to Pyramid Lake. The plant will be operated on-peak whenever possible to help meet project power requirements.

Description

Pyramid Powerplant complex includes the plant, Peace Valley Pipeline, enlarged Quail Canal and Quail Lake facilities, and a switchyard.

The Powerplant will be a 157-megawatt (MW) installation containing two generating units, each turbine capable of passing 1,550 cubic feet per second (cfs) at a static head of 740 feet. The plant will discharge into Pyramid Lake behind Pyramid Dam, which was completed in 1974. It is estimated that the annual generation at this facility will be about 950 million kWh.

Quail Canal and Lake facilities will require modification work to increase their storage capacity and to furnish better control of power generating flows.

Peace Valley Pipeline serves as the penstock for the Powerplant. Two conduits, one for each generating unit, each approximately 5.6 miles in length, will be provided. Construction of this power facility is scheduled to begin in 1977 and be on line in 1982.

Representative preliminary design drawings are included at the end of this chapter.

Geology

The Pyramid Powerplant facilities will lie in the northwest corner of the Ridge Basin, a deep structural basin containing a thick stratigraphic section of Pliocene sedimentary rocks. In this area, rocks consist of sandstones, shales, and siltstones which have been folded into a series of westerly or northwesterly trending folds. Erosional processes have sculptured these rocks into steep-walled canyons and sharp ridges.

Most of the facilities will be in Peace Valley and Cañada de Los Alamos, which combine to form a north-trending valley, floored by alluvial deposits consisting primarily of silts but including some clays, fine-grained sands, and a few gravels. The alluvium, particularly below the Hungry Valley-Peace Valley confluence, is generally saturated from the elevation of the present stream course to the underlying bedrock.

Pipeline

Most of the pipeline will rest on alluvium. Both alluvial deposits and older sedimentary rocks are soft enough that the pipe trench can be excavated by common methods. Some light blasting may be necessary in the sedimentary rocks.

Powerplant Site

The site of the Powerplant is on the west side of Cañada de Los Alamos. The deepest part of the bedrock channel is near the west bank of Peace Valley where maximum depth of alluvium is about 55 feet on the east half of the plant site. It is estimated that approximately the lower 40 feet of alluvium is saturated. The alluvium is expected to be mostly silt, although indications from earlier drilling suggest that there may be a layer of sand and gravel several feet thick immediately overlying the bedrock. Tests of the gravel at another location indicated a permeability of about 24 feet per day.

Below elevation 2,525 feet, the entire plant foundation is expected to be in bedrock. Information from one exploratory hole at the site and other geologic data indicate that bedrock at the plant site is probably silty shale. It is anticipated that the silty shale will be relatively fresh immediately underneath the alluvium. A conservative estimate of bearing capacity of the shale is 6 tons per square foot. The general strike of the sedimentary rocks is northeast, dipping northwesterly between 15 and 20 degrees. This dip is favorable for stability of cuts in bedrock on all sides of the plant except on the southerly side, where the attitude could be conducive to bedding plane-type failures.

Ground Water

The present ground water levels in the valley alluvium in Cañada de Los Alamos are near streambed elevation.

Excavation will be difficult in the saturated alluvial silts, because the silts tend to run and flow and are difficult to dewater. In the alluvial portions of the plant excavation, it may be necessary to excavate much of the silty material beyond the boundaries of the proposed excavation in order to control slopes and ground water.

Seismicity

The project area is near three of California's major faults, the San Andreas, Garlock, and San Gabriel. Both the past seismic history and the tectonic framework of the region suggest that the seismic pattern during the life of the project will be one of strong earthquakes at infrequent intervals. Most likely source of strong earthquakes is the San Andreas fault.

Quail Lake, 8 miles north of Pyramid Powerplant, is within the San Andreas fault zone. It is probable that displacement along the San Andreas fault could affect the Quail Lake facilities, but actual fault displacement is not likely to occur elsewhere.

Exposure to severe earthquake shaking is aggravated by the fact that much of the alluvium in the valley floor is comprised of saturated silts, sands, and clays. These conditions favor earthquake damage by liquefaction, failure of cut slopes particularly where saturated, differential settlements, and lurch-cracking.

Civil Features

Preliminary Studies

Several schemes for developing power on the West Branch of the California Aqueduct were investigated. Of those studied, the following appeared to be the most feasible:

1. A 157-MW powerplant located on the Gorman Creek arm of Pyramid Lake. This plan requires 5,400 acre-feet of active storage in Quail Lake.
2. A 1,200-MW pumped-storage project located on the Piru Creek arm of Pyramid Lake. This alternative required a large dam, reservoir and a realigned pipeline in lieu of Peace Valley Pipeline.
3. A 500-MW pumped-storage project located on the Gorman Creek arm of Pyramid Lake. This project required a 12,000-acre-foot reservoir.

Alternative 1 proved to be the most feasible for construction at this time and has been approved.

Site Development

Access to the powerplant area will be from abandoned State Highway 99, which will remain in service to allow access to the existing recreation area downstream of the plant. Access to State Highway 99 will remain at the Hungry Valley Interchange of Interstate 5 about 2 miles north.

Gorman Creek separates the plant site and Highway 99, and a bridge will be required for access to the plant. The bridge will be a cast-in-place, reinforced-concrete, T-beam bridge of six spans: two 42-foot-long end spans, and four 55-foot-long intermediate spans for a total length of 304 feet. The bridge will be 33 feet - 4 inches wide and will consist of two 14-foot lanes and two 2-foot - 8-inch safety curbs.

The Powerplant will be visible from Interstate 5, and therefore all permanent site grading will be done in a manner that will reduce visual impact of exposed cut and fill slopes. Permanent cuts are planned to be 1½:1, and temporary construction cut slopes will vary from steep to quite shallow depending on the material and ground water level. Final slopes will be based on additional geologic and soil investigations conducted for final design.

Tributary drainage area for the powerplant site is small, and only local runoff has to be accommodated. One small gully discharges from the hills west of the site into the Creek immediately downstream of the plant. Flow will be collected in a culvert and routed into the tailrace channel. Local runoff from the plant site will be collected in drainage ditches and discharged into the Creek downstream of the plant. During construction, storm runoff will be diverted around the powerplant excavation, utilizing permanent drainage facilities where practical.

Spoil from the powerplant excavation will be placed approximately 400 feet behind the plant. The top of the spoil bank will be relatively level and will be used for the switchyard, storage areas, septic tank, and leach field.

Even though Gorman Creek normally has negligible flows, large floodflows do occur. Floodflows from Gorman Creek will discharge into the stilling basin over the vertical north wall of that basin. From this point, the flows will continue into Pyramid Lake by way of the existing channel.

Plant Structure

The substructure will be approximately 149 feet long, 140 feet wide, and 75 feet deep and the superstructure will be about 63 feet high. Plant dimensions will be established by the size of turbine units, arrangement of equipment inside the plant, and space required for the service bay. The invert of the plant will be determined by the required submergence, while the top deck will be set to provide adequate freeboard during flood conditions in Pyramid Lake. The height of the superstructure will be determined by crane clearances required for lifting major equipment. Principal dimensions of the turbine and generators, for preliminary design, will be based on information obtained from manufacturers of this equipment.

The superstructure will be constructed of rigid steel frames enclosed with insulated metal siding and concrete block walls. The steel frames will support the bridge crane. The roof will be metal decking covered with built-up composition roofing. A control room, visitor facilities, and office space will be in a structure attached to the downstream side of the superstructure.

The substructure of the plant will be constructed of reinforced concrete in two stages. The first-stage concrete will essentially complete the substructure, while the second-stage concrete will be used for embedment of the turbines and to support the generators and other plant equipment.

Two draft-tube gates will be provided for dewatering one unit at a time and will be stored in the gate slots immediately below the top deck. The gates will be raised and lowered with a gantry crane.

Waterways

Quail Facilities. These are existing conveyance facilities which require some enlargement to meet the storage requirements of this power development. A full discussion of these facilities is contained in Volume II of this bulletin.

Peace Valley Pipeline. Peace Valley Pipeline will begin at the terminus of lower Quail Canal, extend 5.6 miles to Pyramid Powerplant, and convey the full 3,092-cfs capacity of the West Branch. Elevation differences between the water surfaces in lower Quail Canal and Pyramid Lake will provide an average static head differential of 740 feet. The pipelines will serve as a long penstock.

Studies were made to determine whether a one- or two-barrel pipeline system would be most feasible. These studies compared total costs for installation of various pipe diameters. Information obtained from prestressed pipe suppliers indicated that pipe sections over 10 feet in diameter would be more economically produced by field fabrication and under 10 feet by factory fabrication and transportation to the job site by commercial trucking.

Even though these studies showed the single-pipeline system using a 16-foot diameter to be somewhat less expensive than a two-pipe system each 12 feet in diameter, operational reliability overweighed the economic savings. In addition, heads of the magnitude encountered in Peace Valley Pipeline are unprecedented in 16-foot-diameter pipelines, and the design would have to be extrapolated beyond that considered to be reasonable. Therefore, the two-pipeline system was recommended.

In the vicinity of Pyramid Powerplant, where the backfill cover will be 50 feet, the pipe will be of steel, encased in reinforced concrete to protect it from large overburden loads.

Penstock articulation sections will be provided in the coupling chamber behind the plant where the penstocks enter the structure. These articulation sections will allow for 3 inches of relative displacement in any direction, thus reducing the risk of penstock rupture resulting from displacement or rocking of the plant during an earthquake. The articulation sections will follow the typical designs discussed in Chapter I of this volume.

Afterbay and Tailrace Channel

Design of the afterbay and tailrace channel for Pyramid Powerplant will meet the following basic requirements:

1. Maintain minimum tailwater for the turbines.
2. Convey up to 3,100 cfs from the plant into Pyramid Lake under varying water surface conditions in Pyramid Lake.

A control sill in the invert of the tailrace channel will maintain the required submergence at the units. The tailrace channel will be 260 feet long by 26 feet wide throughout most of its length. In the last 110 feet, it will widen from 26 feet to 74 feet at the stilling basin. The stilling basin will then widen to 104 feet at the calculated location of the hydraulic jump, approximately 35 feet past the end of the tailrace channel. The bottom of the stilling basin will be determined so that the hydraulic jump will match the level of the reservoir when it is at minimum normal operating level.

Mechanical Features

General

Mechanical features are presently in design and will include two turbines, turbine shutoff valves, governors, cranes, and auxiliary equipment.

Chapter I of this volume contains information on mechanical equipment and systems which have been commonly used at other State Water Project plants. Only descriptions of equipment peculiar to this installation are included in the following sections.

Turbines

The Powerplant will house two vertical-shaft Francis-type units operating at 300 rpm and having a capacity of 108,000 horsepower each.

Each turbine will have the capacity to pass 1,550 cfs minimum at near full gate opening. The turbine distributor centerline setting will be at elevation 2,571.5 feet with the tailrace channel designed to provide a water surface 1.5 feet below the turbine centerline under design flow conditions.

The turbine spiral casing and elbow-type draft-tube liner will be embedded in second-stage concrete. The turbine will be designed and constructed so that all removable parts may be hoisted through the generator stator by the main powerplant crane.

Valves

Each unit will have a turbine shutoff valve of approximately the same size as the turbine inlet. The valve will be the spherical double-seated type with a hydraulic cylinder operator. The valve will be complete with an electrohydraulic actuating and control system including cabinet, instruments, controls, sump and pumps, sequencing unit, accumulator, and piping.

Governors

Each turbine will have an electrohydraulic governor similar to the ones installed in other powerplants. They will provide the required turbine speed and load regulation and will be the oil-pressure cabinet-actuator type, with an electrically driven speed responsive element. The governor will be complete with an actuator, restoring mechanism, cabinet, instruments, controls, accumulator, pumps, and piping.

Electrical Features

The electrical equipment and systems will be of conventional design and construction for a two-unit hydroelectric powerplant. Both generators will be rated 82,600 kVA, 95% power factor, 60 degree Celsius rise, 13.8 kV, 300 rpm. The local control system will provide for operation from the plant control room. The control system will be interfaced with the area control system for remote operation.

The following engineering drawings may be found in consecutive order immediately after this reference (Figures 852 through 857).

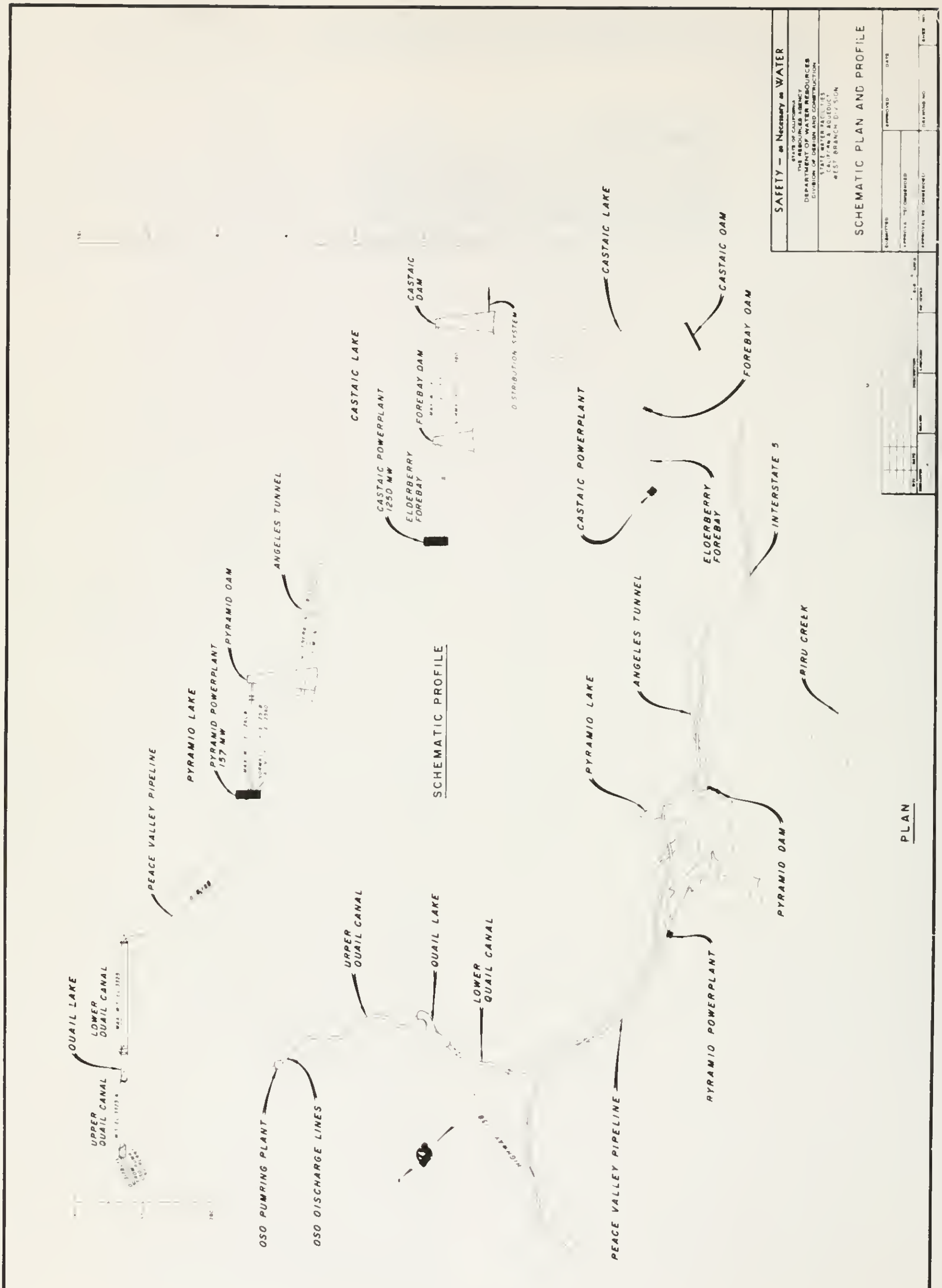


Figure 852. Plan and Profile

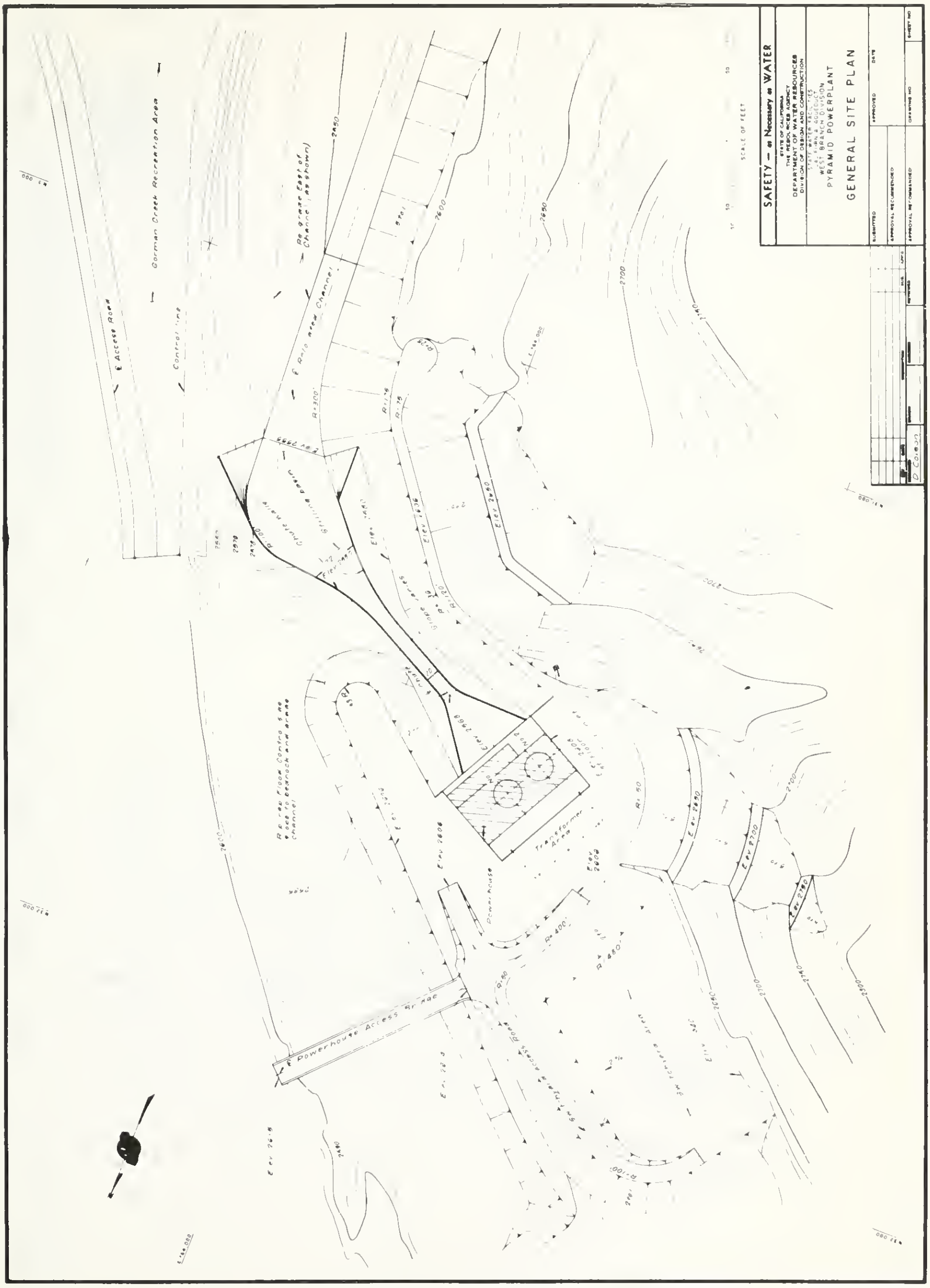


Figure 853. General Site Plan

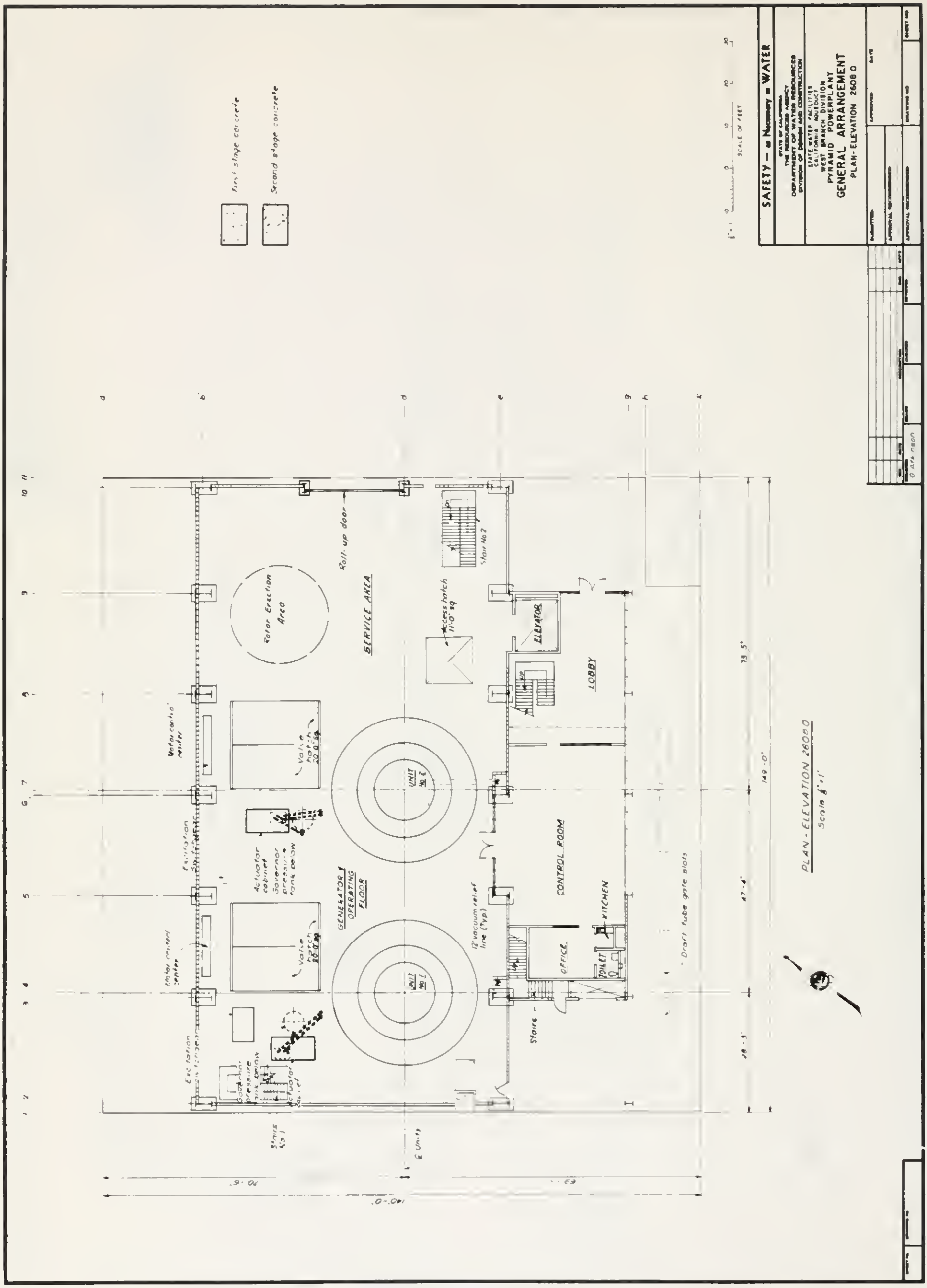


Figure 854. General Arrangement—Elevation 2,608.0

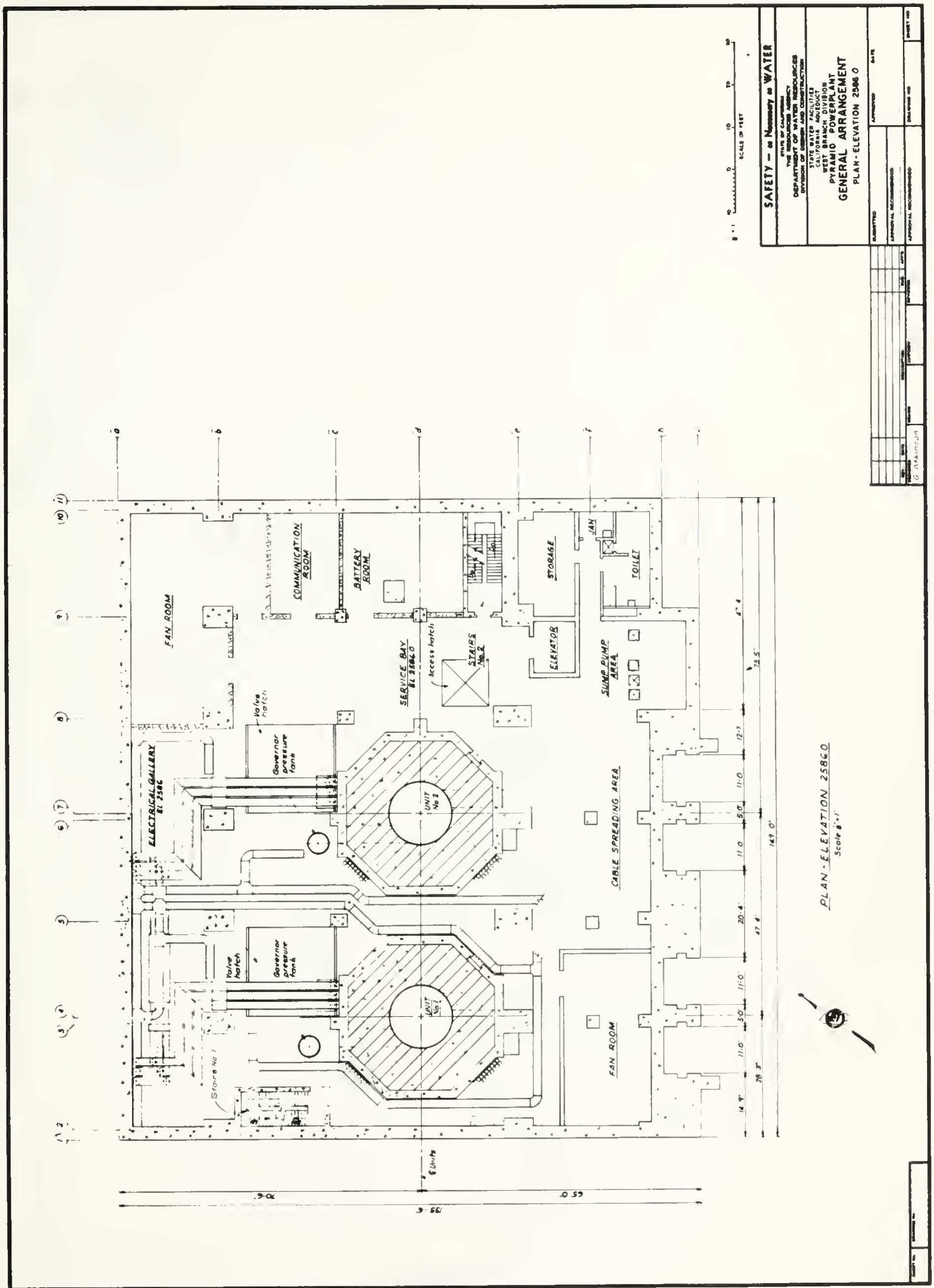


Figure 855. General Arrangement—Elevation 2,586.0

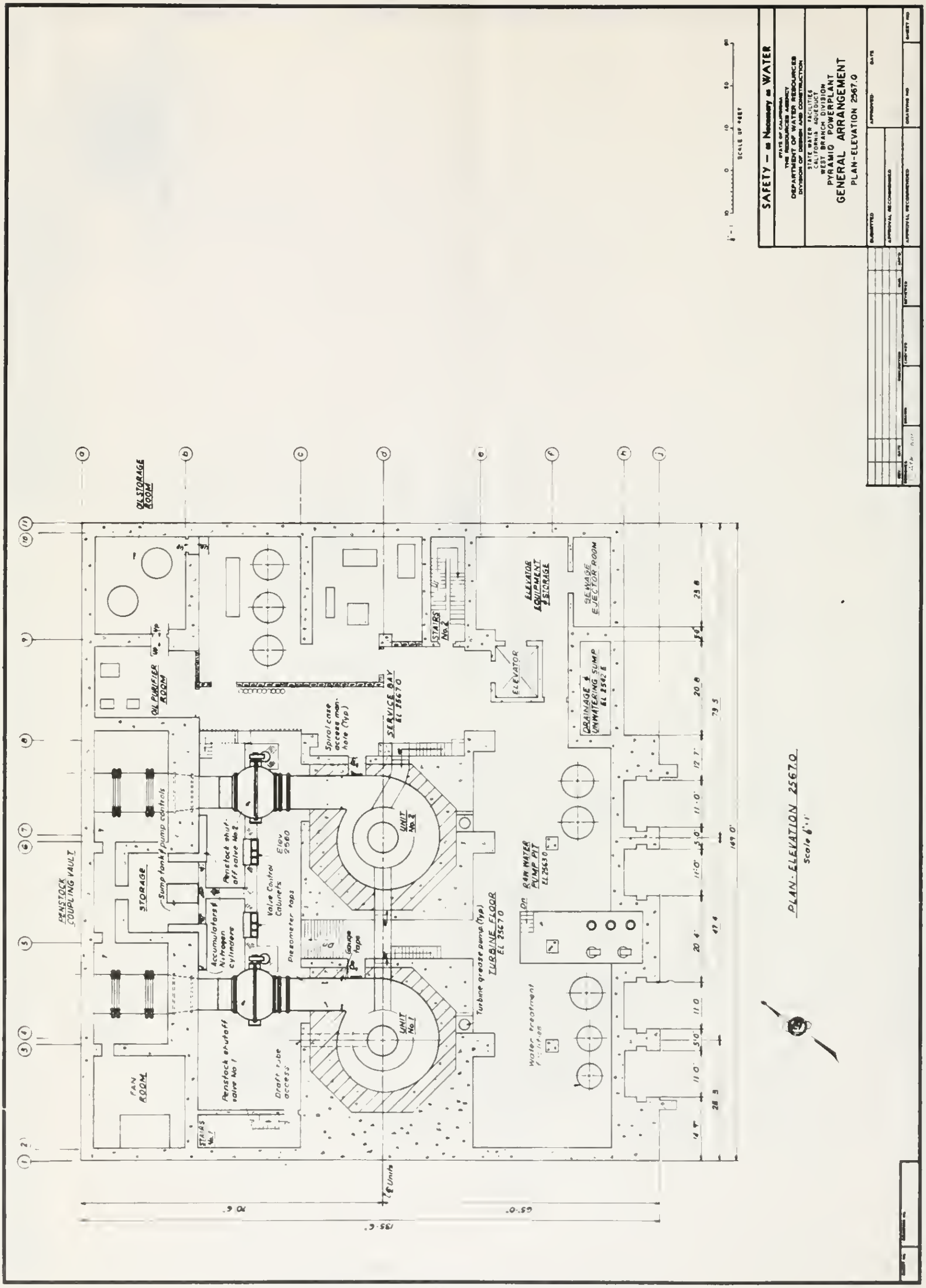


Figure 856. General Arrangement—Elevation 2,567.0

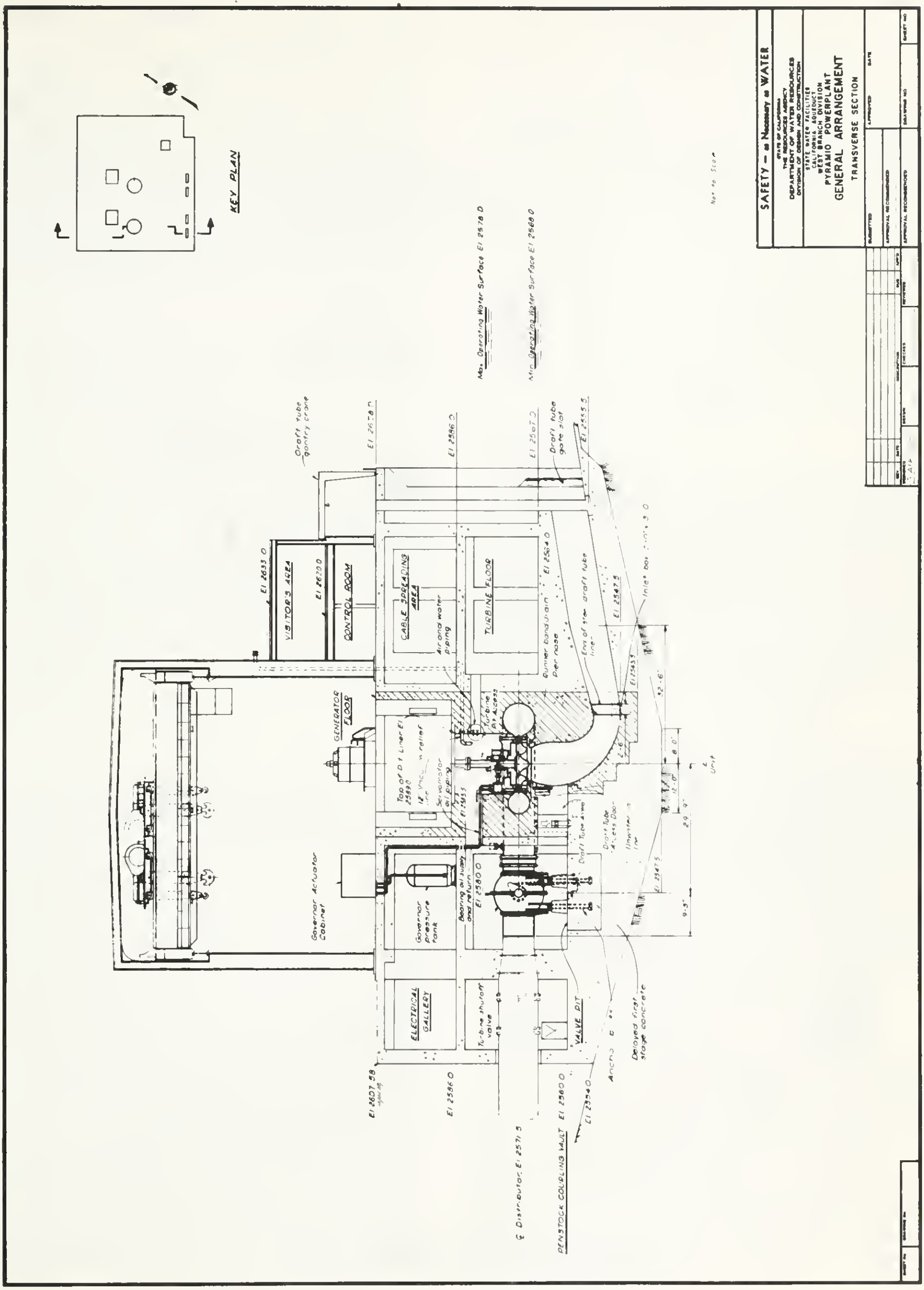


Figure 857. General Arrangement—Transverse Section

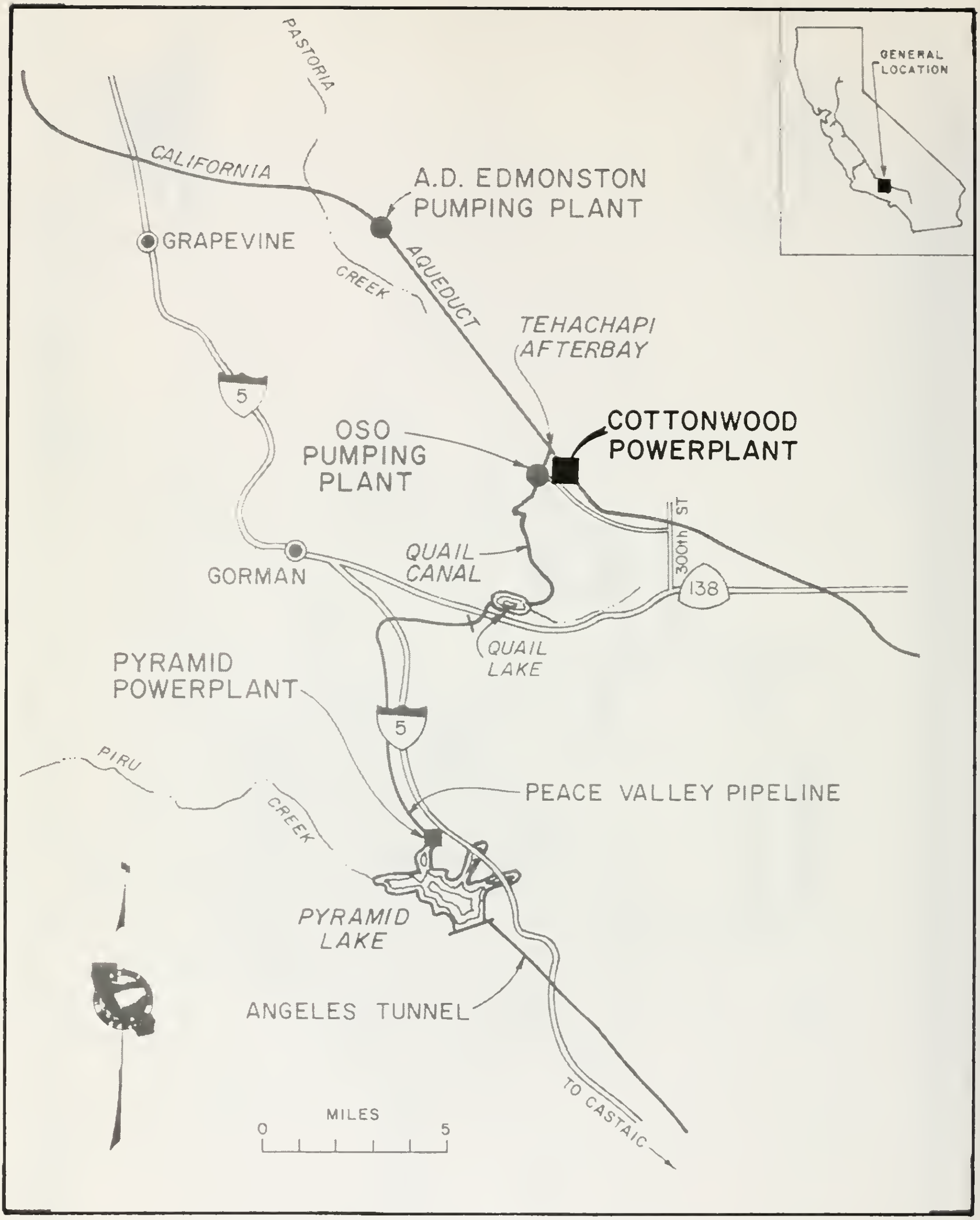


Figure 858. Location Map—Cottonwood Powerplant

CHAPTER XIX. COTTONWOOD POWERPLANT

General

Location

Cottonwood Powerplant is being designed by the Department of Water Resources and is presently scheduled for operation in 1983. The plant will be located approximately 10 miles east of Gorman and 4 miles north of Quail Lake. The Powerplant will be a part of the "main line" California Aqueduct and will be located adjacent to an existing energy-dissipation structure (Figure 858).

Purpose

The Powerplant will utilize the available head drop in the Aqueduct downstream of the bifurcation with the West Branch and will operate in conjunction with scheduled water deliveries.

Description

The Cottonwood Powerplant facilities will include the plant, penstock, tailrace, and intake structure. The plant intake structure will be constructed as a modification to the existing inlet to the chute and dissipator. The chute and energy-dissipation features of the existing facility will be retained for use as a bypass for the plant when the unit is inoperative.

This plant will contain one unit rated at 15 megawatts with a static head of 140 feet. The maximum flow through the unit will be 1,637 cubic feet per second, and total annual energy production will be approximately 115 million kWh.

Geology

Dominant topographic features at the plant site are the flat-topped steep-sided terraces of low relief bordering the flat-floored valley. Geologic formations exposed near the site include a pre-Tertiary bedrock series, lakebed deposits, and Older and Younger alluvium of Recent Age.

Uplift of the Tehachapi Mountains, and the accompanying faulting and erosion, developed in irregular stages over a long period of time. Most of the faulting is restricted to the base of the Tehachapi Mountain front and does not extend into the plant area. The recent alluvium and, so far as is known, the Older alluvium in the site area have not been deformed.

The plant site is approximately 4 miles northeast of the San Andreas fault zone and about 4 miles southeast of the Garlock fault zone. In addition to these two major faults, several smaller faults traverse the west end of Antelope Valley and transect the front of the Tehachapi Mountains. Although there is good evidence for geologically recent movement on these faults, only the San Andreas has been active historically. Further movement at some time in the future is a probability, and some damage to facilities by shaking is possible.

Civil Features

Site Development

Access to the Powerplant will be from State Highway 138 on existing project roads. Development of the plant site will consist of modifying the existing energy-dissipation bowl to accommodate the proposed structure.

Plant Structure

The substructure will be approximately 78 feet long, 83 feet wide, and 70 feet deep, constructed of reinforced concrete. The superstructure will be approximately 40 feet high, constructed of rigid frames enclosed with insulated metal siding and concrete block walls. The roof will be metal decking covered with built-up composition roofing.

Waterways

The intake to the penstock will be a modification of the existing inlet structure and will utilize one of the existing radial gates for inlet control to the penstock.

The penstock will be an 11-foot-diameter, prestressed-concrete, buried pipe approximately 3,500 feet long.

The tailrace outlet transition will join the canal just downstream of the existing energy-dissipator stilling basin. Formed concrete walls and a sloped, paved, transition section will connect the powerplant tailrace to the existing canal.

Mechanical Features

Mechanical features at Cottonwood Powerplant will include a turbine, governor, crane, and auxiliary equipment. No turbine shutoff valve will be provided at this installation, since this will be a single-unit plant with one penstock; a radial gate at the intake is provided for penstock closure for maintenance.

Chapter I of this volume contains information on mechanical equipment and systems which have been commonly used at other project plants. Descriptions of equipment expected to be used at this installation are included in the following sections.

Turbine

The Powerplant will contain one vertical-shaft Francis-type unit operating at 200 rpm with a capacity of 22,500 horsepower. The turbine will be direct-connected to a vertical-shaft synchronous generator. The distributor centerline setting will be at elevation 2,963 feet, 4 feet above the normal tailwater surface.

The spiral casing and draft-tube liner will be embedded in the second-stage concrete of the plant substructure. The turbine will be designed to permit removal of parts through the generator stator by the main powerplant crane.

Governor

The governor will provide turbine speed regulation and will be an oil-pressure cabinet-actuator type with an electrically driven speed responsive element. It will be complete with an actuator, restoring mechanism, cabinet, instruments, controls, accumulator, pumps, and piping.

Crane

The crane will be a 100-ton, electric, overhead, single-trolley, cab-operated, bridge type with a span of approximately 59 feet and will be used for equipment installation and maintenance.

Electrical Features

Electrical equipment and systems will be of conventional design and construction for a single-unit hydroelectric power plant. The generator will be rated 18,000 kVA, 95% power factor, 60 degree Celsius rise, 13.8 kV, 200 rpm. The local control system will provide for operation of the unit from the plant control room. The local control system will be interfaced with the Castaic Area Control Center for remote operation. No switchyard will be provided on-site. Switching for the plant will be provided by an extension of the existing switchyard at nearby Oso Pumping Plant with interconnecting transmission lines.

APPENDIX A

BIBLIOGRAPHY

APPENDIX A

BIBLIOGRAPHY

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APPENDIX B

CONSULTING BOARDS

AND

ORGANIZATIONS

APPENDIX B

CONSULTING BOARDS AND ORGANIZATIONS

Earthquake Analysis Board

Dr. Clarence Allen
Dr. Hugo Benioff
Dr. John Blume
Dr. Bruce Bolt
Dr. George Housner
Dr. H. Bolton Seed
Dr. James L. Sherard
Mr. Nathan D. Whitman

This board advised the Department concerning the evaluation of probable seismic effects at any given site or area and on the development of rational procedures for seismic design of hydraulic structures.

Oroville Dam Consulting Board

Mr. A. H. Ayers
Mr. John Hammond
Mr. Raymond A. Hill
Mr. J. Donovan Jacobs
Mr. Thomas A. Lang
Mr. Roger Rhoades
Dr. Philip C. Rutledge
Mr. Byram W. Steele
Mr. B. E. Torpen

This board advised the Department's engineers on design and construction of Oroville Dam and Hyatt-Thermalito power complex.

Tehachapi Crossing Consulting Board

Major General John R. Hardin, Ret.
Mr. Russell Hornberger
Mr. Thomas Leps
Mr. Elmer C. Marliave
Dr. Frank A. Nickell
Mr. John Parmakian
Mr. Louis Puls
Mr. Robert Sailer

This board advised the Department's engineers on the design and construction of the Tehachapi crossing. The Tehachapi crossing, insofar as the Board's assignment was concerned, extends from the Buena Vista Pumping Plant on the California Aqueduct to Castaic reservoir outlet works at the end of the West Branch but excludes both Pyramid and Castaic Dams. Their assignment also included the Pearblossom Pumping Plant, Devil Canyon Powerplant, and the San Bernardino Tunnel on the "main line" (East Branch) of the California Aqueduct.

International Engineering Company—San Francisco, California
Designs, plans, and specifications for:
Wind Gap Pumping Plant
Hyatt-Thermalito-Table Mountain Transmission Line

Bechtel Corporation—San Francisco, California
Designs, plans, and specifications for:
Oso Pumping Plant

Sverdrup and Parcel & Associates—San Francisco, California
Designs, plans, and specifications for:
Edward Hyatt Powerplant Intake Gate and Gantry Cranes

Daniel, Mann, Johnson, & Mendenhall—Los Angeles, California
A. D. Edmonston Pumping Plant Pump Model Program

University of California at Davis, California
Model studies for:
A. D. Edmonston Pumping Plant Intake Hydraulics
Thermalito Powerplant Intake Hydraulics
Angeles Tunnel Intake Hydraulics
Edward Hyatt Intake Hydraulics During Pumpback

U. S. Bureau of Reclamation—Denver, Colorado
Model studies for:
Edward Hyatt Intake Gate Hydraulics During Pumpback
Edward Hyatt Draft-Tube Connections and Tailrace Surges

APPENDIX C

ENGLISH TO METRIC CONVERSIONS

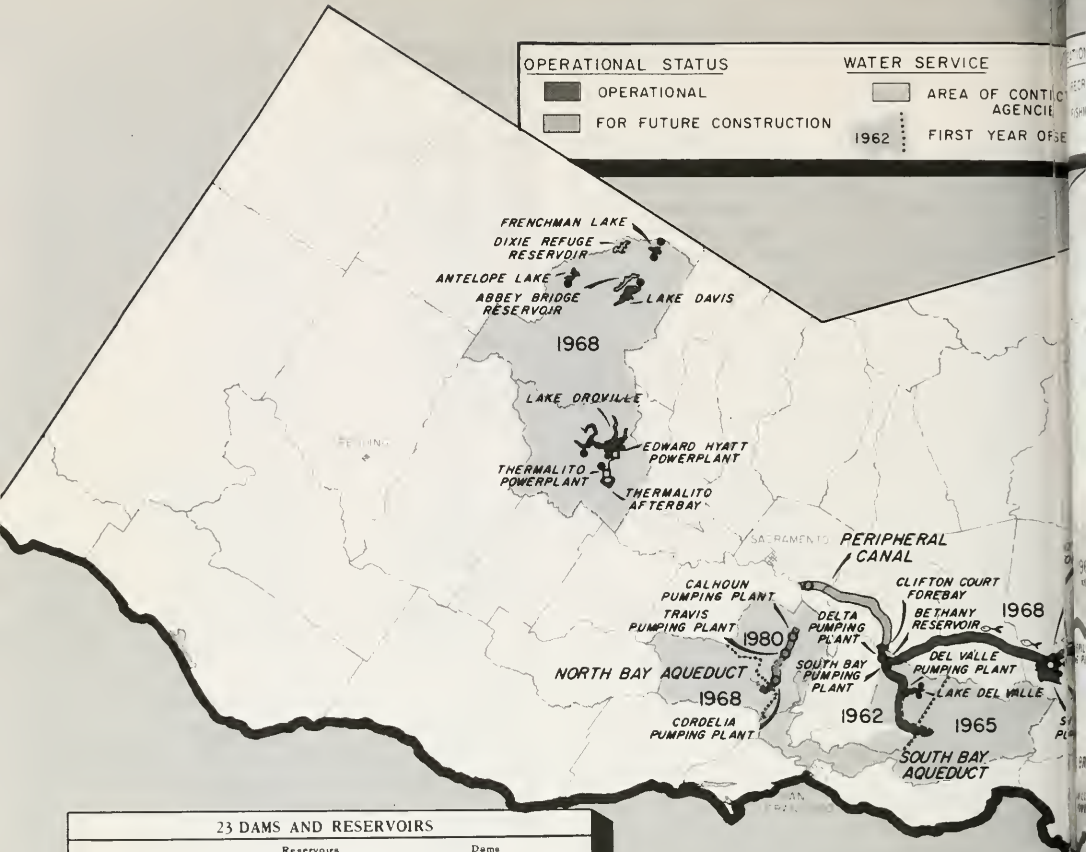
AND PROJECT STATISTICS

CONVERSION FACTORS

English to Metric System of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches	2.54	centimeters
	feet	30.48	centimeters
		0.3048	meters
		0.0003048	kilometers
	yards	0.9144	meters
	miles	1,609.3	meters
		1.6093	kilometers
Area	square inches	6.4516	square centimeters
	square feet	929.03	square centimeters
	square yards	0.83613	square meters
	acres	0.40469	hectares
		4,046.9	square meters
		0.0040469	square kilometers
	square miles	2.5898	square kilometers
Volume	gallons	3,785.4	cubic centimeters
		0.0037854	cubic meters
		3.7854	liters
	acre-feet	1,233.5	cubic meters
		1,233,500.0	liters
	cubic inches	16.387	cubic centimeters
	cubic feet	0.028317	cubic meters
	cubic yards	0.76455	cubic meters
		764.55	liters
Velocity	feet per second	0.3048	meters per second
	miles per hour	1.6093	kilometers per hour
Discharge	cubic feet per second or second-feet	0.028317	cubic meters per second
Weight	pounds	0.45359	kilograms
	tons (2,000 pounds)	0.90718	tons (metric)
Power	horsepower	0.7460	kilowatts

PROJ



23 DAMS AND RESERVOIRS

Name of Reservoir	Reservoirs: Gross Capacity(1 (Acre-feet)	Reservoirs: Surface Area (acres)	Reservoirs: Shore-line (miles)	Dams: Structural Height (feet)	Dams: Crest Elevation(2 (feet)	Dams: Crest Length (feet)	Dams: Volume (cubic yards)
Frenchman Lake	55,477	1,580	21	139	5,607	720	537,000
Antelope Lake	22,566	931	15	120	5,025	1,320	380,000
Lake Davis	84,371	4,026	32	132	5,785	800	253,000
Abbey Bridge	45,000	1,950	21	117	5,4[illegible]	1,150	500,000
Dixie Refuge	16,000	900	15	100	5,754	1,050	400,000
Lake Oroville	3,537,577	15 805	167	770	922	6,920	80,000,000
Thermalito Diversion Pool	13,328	323	10	143	233	1,300	154,000
Fish Barrier Pool	580	52	1	91	181	600	10,500
Thermalito Forebay	11,768	630	10	91	231	15,900	1,840,000
Thermalito Afterbay	57,041	4 302	26	39	142	42,000	5,020,000
Clifton Court Forebay	28,653	2,109	8	30	14	36,500	2 440,000
Bethany	4,804	161	6	121	250	3,940	1,400,000
Lake Del Valle	77,106	1,060	16	235	773	880	4,150,000
San Luis	2,038,771	12,700	65	385	554	18,600	77,645,000
O'Neill Forebay	56,426	2,700	12	88	233	14 350	3,000,000
Los Banos	34,562	623	12	167	384	1,370	2,100,000
Little Panoche	13,236	354	10	152	676	1,440	1,210,000
Buttes	21,800	580	6	190	2,790	2,230	3,130,000
Silverwood Lake	74,970	976	13	249	3,378	2,230	7,600,000
Lake Perris	131 452	2,318	10	128	1,600	11,600	20,000,000
Pyramid Lake	171,196	1,297	21	400	2,606	1,090	6,860,000
Elderberry Forebay	28,231	460	7	200	1,550	1,990	6,000,000
Castaic Lake	323,702	2,235	29	425	1,535	4,900	46,000,000
Totals	6,848,617	58,072	533			172,880	270,629,500

1) At maximum normal operating level.

2) Above sea level.

AQUEDUCTS

Name	Length (miles): Total	Canal	Pipeline	Tunnel	Channel and Reservoir
North Bay Aqueduct	26.5	14 3	12.2	0	0
South Bay Aqueduct	42.9	8 4	32 9	1.6	0
Peripheral Canal	43.0	42.0	1.0	0	0
Subtotal	112.4	64 7	46.1	1.6	0
California Aqueduct (main line):					
Delta to O'Neill Forebay	68.4	67.0	0	0	1 4
O'Neill Forebay to Kettleman City	105.7	103 5	0	0	2.2
Kettleman City to A. D. Edmonston Pumping Plant	120 9	120.9	0	0	0
A. D. Edmonston Pumping Plant thru Tehachapi Afterbay	10 6	0.2	2.5	7 9	0
Tehachapi Afterbay thru Lake Perris	138 4	93 4	38 3	3 8	2.9
Subtotal, main line	444.0	365 0	40 6	11 7	6 5
California Aqueduct (branches):					
West Branch	31.9	9.1	6.4	7.2	9 2
Coastal Branch	96 2	14 8	81 4	0	0
Subtotal, branches	128.1	23 9	87 8	7.2	9.2
Totals	684.5	473 8	174 7	20.5	15.7

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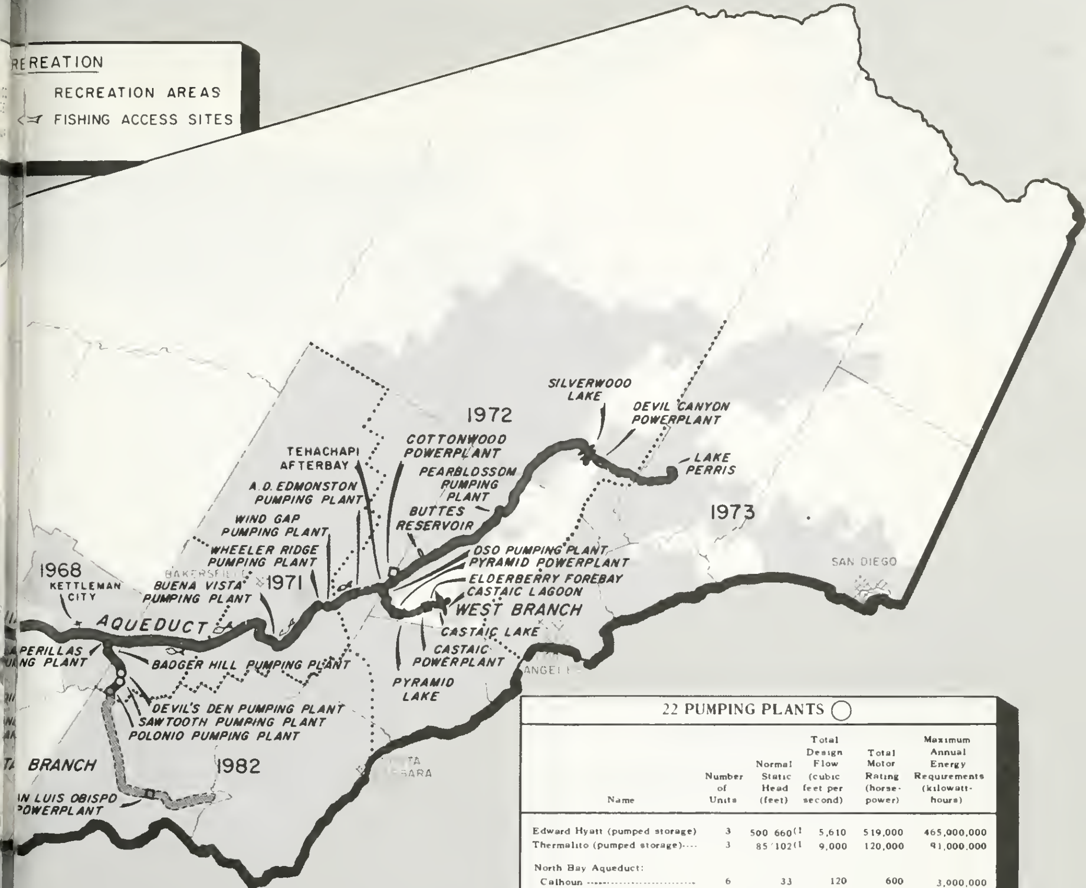


8 POWERPLANTS

Name	Number of Units	Normal Static Head (feet)	Total Design Flow (cubic feet per second)	Power Generator Output (kilowatts)	Maximum Annual Energy Output (kilowatt-hours)
Edward Hyett	6	410/676[1]	14,550	678,750	2,475,000,000
Thermalito	4	85/100[1]	16,900	119,600	383,000,000
San Luis					
Total	8	99/327[1]	13,120	424,000	
State Share			6,872	222,100	170,000,000
Cottonwood	1	140	1 637	15,000	115,000,000
Devil Canyon	2	1,418	1 200	119,700	1,003,000,000
Pyramid	2	740	3,100	157,000	1,001,000,000
Castaic					
Total	7	1,063	18,400	1,250,000	
State Share[2]			3,092	214,000	1,457,000,000
San Luis Obispo	1	730	111	5,900	41,000,000
Total, State Share					6,645,000,000

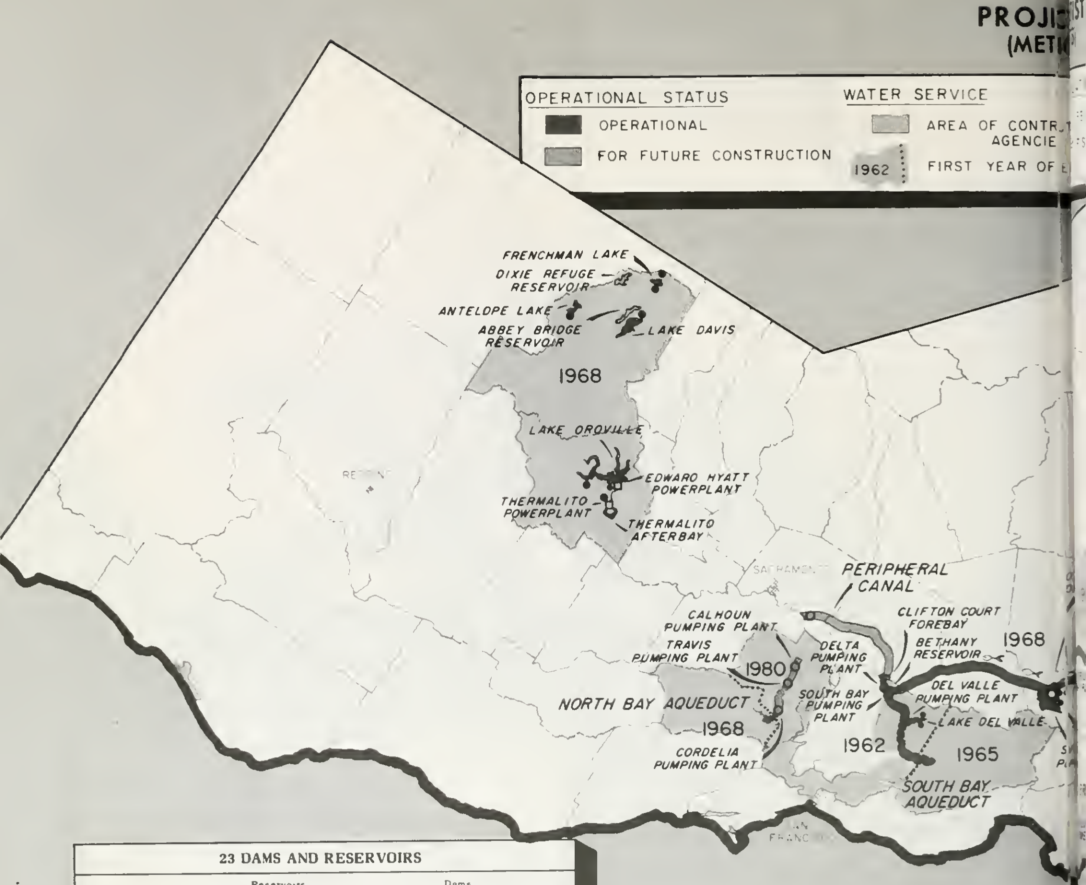
1) Minimum and maximum static heads

2) The City of Los Angeles Department of Water and Power will construct and operate a 1,250,000-kilowatt Castaic Powerplant and will supply the Project with electrical power and energy equivalent to the generation from a 213,984 kilowatt powerplant the State originally planned to construct

22 PUMPING PLANTS

Name	Number of Units	Normal Static Head (feet)	Total Design Flow (cubic feet per second)	Total Motor Rating (horse-power)	Maximum Annual Energy Requirements (kilowatt-hours)
Edward Hyatt (pumped storage)	3	500 660[1]	5,610	519,000	465,000,000
Thermalito (pumped storage)	3	85/102[1]	9,000	120,000	91,000,000
North Bay Aqueduct:					
Calhoun	6	33	120	600	3,000,000
Travis	6	0	120	900	5,000,000
Cordelia	3	448	48	3,100	14,000,000
South Bay Aqueduct:					
South Bay	9	545	330	27,750	166,000,000
Del Valle	4	0/38[2]	120	1,000	2,000,000
California Aqueduct (main line):					
Delta	11	244	10,303	333,000	1,355,000,000
San Luis					
Total	8	99 327[2]	11,000	504,000	
State Share			5,762	264,000	313,000,000
Dos Amigos					
Total	6	113	13,200	240,000	
State Share			7,100	130,000	607,000,000
Buena Vista	10[3]	205	5,049	136,000	746,000,000
Wheeler Ridge	9[3]	233	4,598	140,000	797,000,000
Wind Gap	9[3]	518	4,410	308,000	1,761,000,000
A. D. Edmonston	14[3]	1,926	4,095	1,040,000	5,916,000,000
Pearblossom	6	540	1,380	113,200	647,000,000
California Aqueduct (branches):					
Oso	8	231	3,128	93,800	446,000,000
Las Perillas	6	55	450	4,050	20,000,000
Badger Hill	6	151	450	10,500	56,000,000
Devil's Den	4	409	126	8,000	51,000,000
Sawtooth	4	331	126	6,500	41,000,000
Polonio	4	810	126	16,000	101,000,000
Peripheral Canal					
Total	9[3]	10	21,800	35,200	
State Share			10,900	17,440	88,000,000
Total, State Share					13,691,000,000

1) Minimum and maximum total pumping heads.
2) Minimum and maximum static heads.
3) Includes one spare unit.



23 DAMS AND RESERVOIRS

Name of Reservoir	Reservoirs: Gross Capacity[1] (millions of cubic meters)	Reservoirs: Surface Area (hectares)	Reservoirs: Shoreline (kilometers)	Dams: Structural Height (meters)	Dams: Crest Elevation[2] (meters)	Dams: Crest Length (meters)	Dams: Volume (cubic meters)
Frenchman Lake	68.43	639	33.8	42	1709	219	410,600
Antelope Lake	27.84	377	24.1	37	1532	402	290,500
Lake Davis	104.07	1,629	51.5	40	1763	244	193,400
Abbey Bridge	55.51	789	33.6	36	1669	351	382,300
Dixie Refuge	19.74	364	24.1	30	1754	320	305,800
Lake Oroville	4,363.60	6,396	268.8	235	261	2,109	61,164,000
Thermalito Diversion Pool	16 44	131	16 1	44	71	396	117,700
Fish Barrier Pool	0.72	21	1.6	28	55	183	8,000
Thermalito Forebay	14.52	255	16.1	28	70	4,846	1,406,800
Thermalito Afterbay	70.36	1,741	41.8	12	43	12,802	3,838,000
Clifton Court Forebay	35.34	853	12.9	9	4	11,125	1,865,500
Bethany	5.93	65	9.7	37	76	1,201	1,070,300
Lake Del Valle	95.11	429	25.6	72	236	268	3,172,900
San Luis	2,514.82	5,140	104.6	117	169	5,669	59,363,500
O'Neill Forebay	69.60	1,093	19.3	27	71	4,374	2,293,700
Los Banos	42.63	252	19 3	51	117	416	1,605,600
Little Panoche	16.33	143	16 1	46	206	439	925,100
Buttes	26.89	235	9.7	56	650	680	2,393,000
Silverwood Lake	92.46	395	20.9	76	1,030	680	5,610,600
Lake Perris	162.15	938	16 1	39	488	3,536	15,291,000
Pyramid Lake	211.17	525	33.6	122	794	332	5,244,800
Elderberry Forebay	34 82	186	11 3	61	472	607	4,587,300
Castaic Lake	399 29	904	36.7	130	466	1,494	35,169,300
Totals	8,447 79	23,500	857.9			52,695	206,909,700

1/ At maximum normal operating level.
2/ Above sea level.

AQUEDUCTS

Name	Length (kilometers): Total	Canal	Pipeline	Tunnel	Channel and Reservoir
North Bay Aqueduct	42.6	23 0	19 6	0	0
South Bay Aqueduct	69.1	13.5	53.0	2.6	0
Peripheral Canal	69.2	67 6	1 6	0	0
Subtotal	180.9	104.1	74.2	2.6	0
California Aqueduct (main line):					
Delta to O'Neill Forebay	110.1	107.8	0	0	2.3
O'Neill Forebay to Kettleman City	170.1	166 6	0	0	3.5
Kettleman City to A.D. Edmonston Pumping Plant	194.6	194.6	0	0	0
A.D. Edmonston Pumping Plant thru Tehachapi Afterbay	17 0	0 3	4 0	12 7	0
Tehachapi Afterbay thru Lake Perris	222 7	150 3	61 6	6 1	4 7
Subtotal, main line	714.5	619 6	65 6	18 8	10.5
California Aqueduct (branches):					
West Branch	51.3	14.6	10.3	11.6	14.8
Coastal Branch	154.8	23.8	131.0	0	0
Subtotal, branches	206 1	38 4	141.3	11 6	14 8
TOTALS	1,101.5	762.1	281.1	33.0	25.3

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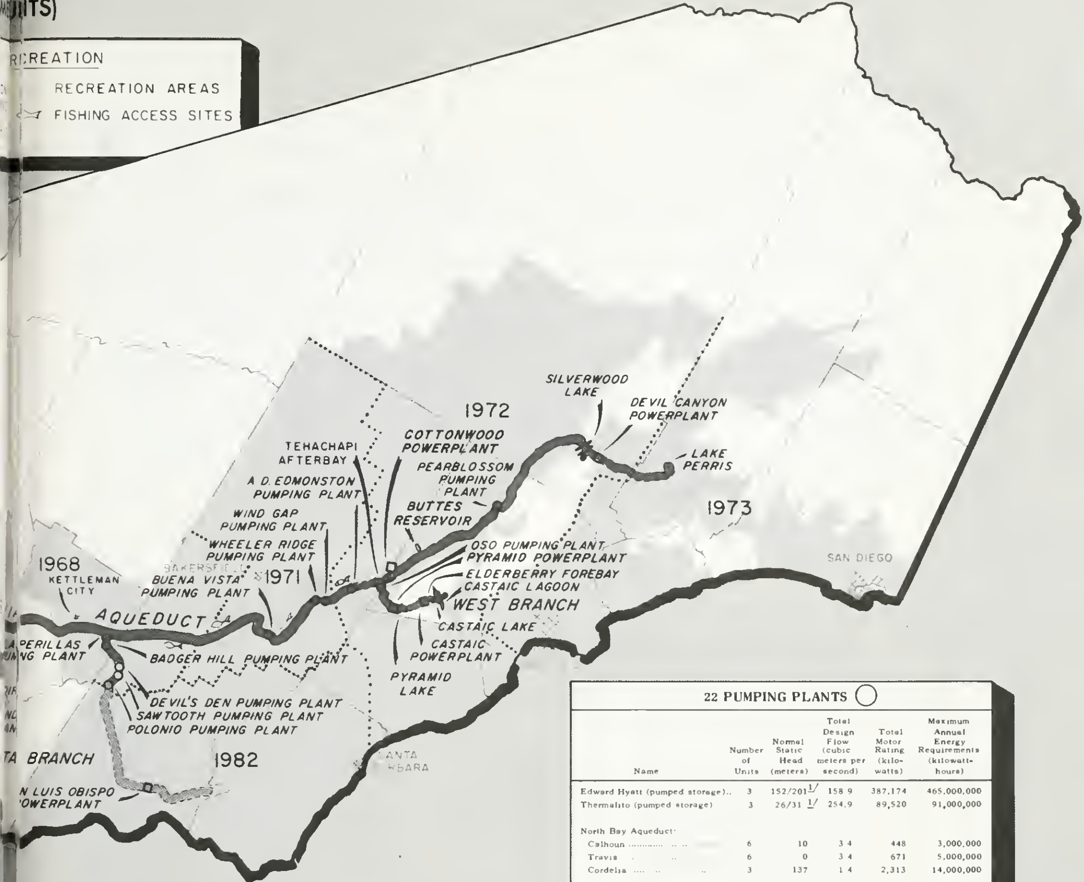

8 POWERPLANTS

Name	Number of Units	Normal Static Head (meters)	Total Design Flow (cubic meters per second)	Power Generator Output (kilowatts)	Maximum Annual Energy Requirements (kilowatt-hours)
Edward Hyatt	6	125/206 1/	412.0	678,750	2,475,000,000
Thermalito	4	26/30 1/	478.6	119,600	383,000,000
San Luis					
Total	8	30/100 1/	371.6	424,000	
State Share			194.6	222,100	170,000,000
Cottonwood	1	43	46.4	15,000	115,000,000
Devil Canyon	2	432	34.0	119,700	1,003,000,000
Pyramid	2	226	87 8	157,000	1,001,000,000
Castaic					
Total	7	324	521.0	1,250,000	
State Share 2/			87.6	214,000	1,457,000,000
San Luis Obispo	1	223	3 1	5,900	41,000,000
Total, State Share					6 645,000,000

1/ Minimum and maximum static heads.

2/ The City of Los Angeles Department of Water and Power will construct and operate a 1,250,000-kilowatt Castaic Powerplant and will supply the Project with electrical power and energy equivalent to the generation from a 213,984-kilowatt powerplant the State originally planned to construct

22 PUMPING PLANTS

Name	Number of Units	Normal Static Head (meters)	Total Design Flow (cubic meters per second)	Total Motor Rating (kilo-watts)	Maximum Annual Energy Requirements (kilowatt-hours)
Edward Hyatt (pumped storage)	3	152/201 1/	158 9	387,174	465,000,000
Thermalito (pumped storage)	3	26/31 1/	254.9	89,520	91,000,000
North Bay Aqueduct:					
Calhoun	6	10	3 4	448	3,000,000
Travis	6	0	3 4	671	5,000,000
Cordelia	3	137	1 4	2,313	14,000,000
South Bay Aqueduct:					
South Bay	9	166	9.3	20,702	166,000,000
Del Valle	4	0/12 2/	3.4	746	2,000,000
California Aqueduct (main line):					
Delta	11	74	291.8	248,418	1,355,000,000
San Luis					
Total	8	30/100 2/	311.5	375,984	
State Share			163.2	196,944	313,000,000
Dos Amigos					
Total	6	34	373 8	179,040	
State Share			201 1	96,980	607,000,000
Buena Vista	10 3/	62	143.0	101,456	746,000,000
Wheeler Ridge	9 3/	71	130 2	104,440	797,000,000
Wind Gap	9 3/	158	124.9	229,768	1,761,000,000
A.D. Edmonston	14 3/	587	116.0	775,840	5,916,000,000
Pearblossom	6	165	39 1	84,447	647,000,000
California Aqueduct (branches):					
Oso	8	70	88 6	69,975	446,000,000
Las Perillas	6	17	12 7	3,021	20,000,000
Badger Hill	6	46	12 7	7,835	56,000,000
Devil's Den	4	125	3.6	5,968	51,000,000
Sawtooth	4	101	3.6	4,849	41,000,000
Polonio	4	247	3 6	11,936	101,000,000
Peripheral Canal					
Total	9	3	617.3	26,259	
State Share			308 7	13,010	88,000,000
Total, State Share					13,691,000,000

1/ Minimum and maximum total pumping heads

2/ Minimum and maximum static heads.

3/ Includes one spare unit.

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